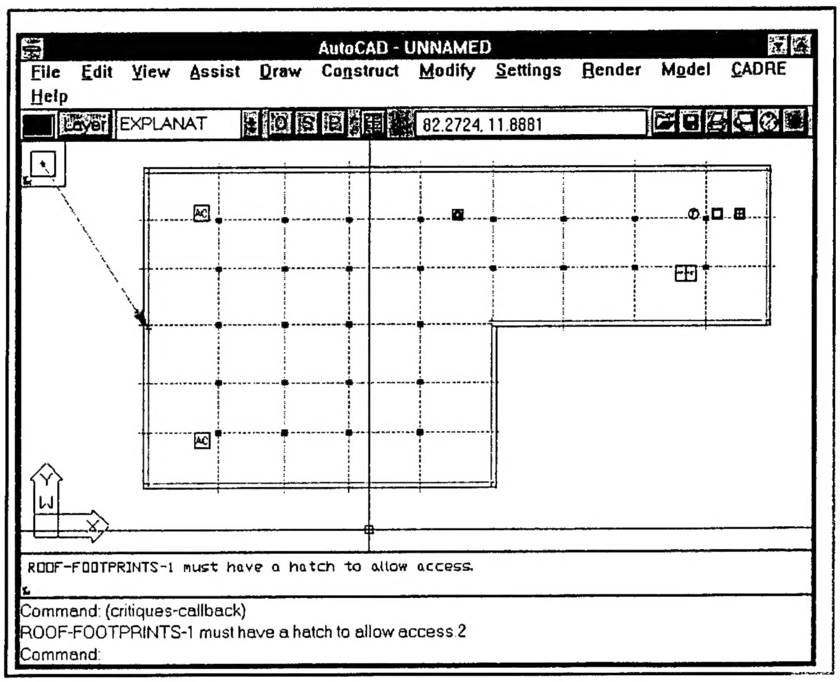
US Army Corps
of Engineers
Construction Engineering
Research Laboratories

USACERL Technical Report 97/37
April 1997

The SEDAR Reuse Libraries

by
Michael C. Fu, Jonathan E. Dapin, and E. William East



The Support Environment for Design And Review (SEDAR) System is an expert critiquing system for flat and low-slope roof design developed at the U.S. Army Construction Engineering Research Laboratories. SEDAR uses a task-based model of design for flexible control of its multi-strategy critiquing abilities. It is designed to support the existing design and review protocol for roof design for the U.S. Army Corps of Engineers.

This report describes reusable components of SEDAR. The components are: the expert critiquing shell, the flat and low-slope roof design domain knowledge base, a set of two-dimensional geometric reasoning routines, and a set of AutoCAD™ functions for information display. Each component's structure is described in detail, and necessary modifications for effective reuse are discussed. The appendices to this report contain file specifications and an index of the functions, rules, and rule sets of SEDAR.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave Blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	April 1997	Final

4. TITLE AND SUBTITLE
The SEDAR Reuse Libraries

5. FUNDING NUMBERS
4A162784
AT41
AR6

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Construction Engineering Research Laboratories (USACERL)
P.O. Box 9005
Champaign, IL 61826-9005

8. PERFORMING ORGANIZATION REPORT NUMBER
TR 97/37

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Headquarters, U.S. Army Corps of Engineers (HQUSACE)
ATTN: CEMP-CE
20 Massachusetts Avenue NW.
Washington, DC 20314-1000

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Copies are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

The Support Environment for Design And Review (SEDAR) System is an expert critiquing system for flat and low-slope roof design developed at the U.S. Army Construction Engineering Research Laboratories. SEDAR uses a task-based model of design for flexible control of its multi-strategy critiquing abilities. It is designed to support the existing design and review protocol for roof design for the U.S. Army Corps of Engineers.

This report describes reusable components of SEDAR. The components are: the expert critiquing shell, the flat and low-slope roof design domain knowledge base, a set of two-dimensional geometric reasoning routines, and a set of AutoCAD™ functions for information display. Each component's structure is described in detail, and necessary modifications for effective reuse are discussed. The appendices to this report contain file specifications and an index of the functions, rules, and rule sets of SEDAR.

14. SUBJECT TERMS
Support Environment for Design And Review (SEDAR)
roofs
design criteria
knowledge based systems
expert systems
computer aided design

15. NUMBER OF PAGES
128

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	SAR

Foreword

This study was conducted for the Directorate of Military Programs, Headquarters, U.S. Army Corps of Engineers (HQUSACE) under Project 4A162784AT41, "Military Facilities Engineering Technology"; Work Unit AR6, "Domain Knowledge Structure and Process." The technical monitors were Robert Chesi, CEMP-CE and Stan Green, CEMP-CE.

The work was performed by the Engineering Processes Division (PL-E) of the Planning and Management Laboratory (PL), U.S. Army Construction Engineering Research Laboratories (USACERL). Dr. Michael P. Case is Chief, CECER-PL-E, and L. Michael Golish is Operations Chief, CECER-PL. The USACERL technical editor was Linda L. Wheatley, Technical Information Team.

The Roof Consultants Institute (RCI) provided computer-aided design (CAD) roof symbols for the project. IBM-PC, Microsoft Windows, Goldworks III, and AutoCAD are registered trademarks of International Business Machines, Microsoft, Gold Hill Computers, and Autodesk, respectively.

COL James T. Scott is Commander and Dr. Michael J. O'Connor is Director of USACERL.

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1 Introduction

Background

The Support Environment for Design And Review (SEDAR) System is an expert critiquing system intended to support designers and reviewers in the domain of flat and low-slope roof design. Based on the IBM-PC hardware platform and the Microsoft Windows operating system, it uses a commercial, LISP-based expert system shell (Goldworks III) and a commercial computer-assisted design (CAD) program (AutoCAD). By providing an interactive, graphical interface for roof designers and reviewers, SEDAR is intended to increase the efficiency of the design review process.

Objective

The objective of this study was to identify and describe reusable components of the SEDAR project. This effort will help future developers interested in creating expert critiquing systems for other problem domains or in creating systems using the commercial applications mentioned above.

Approach

The SEDAR project has been supported by the U.S. Army Construction Engineering Research Laboratories (USACERL) since 1994. The initial architecture for the system was created after a thorough review of state-of-the-art construction management systems and existing documents from the U.S. Army Corps of Engineers. Preliminary testing of the SEDAR project for flat and low-slope roof design was conducted from May through June 1995. The testing led to revisions in the system involving the user interface. Finally, the existing SEDAR code was documented and reorganized in preparation for this report.

Scope

The SEDAR project acts as an agent in the ACE collaborative engineering project developed at USACERL and may also act as a standalone expert critiquing system. Currently SEDAR is in a second development cycle to incorporate enhancements from the testing phase and additional planned extensions.

Mode of Technology Transfer

The code developed under the SEDAR project is documented in this report. A diskette containing the reuse library files described in this report will be available upon request. The algorithms developed under this project will also be applied to the development of modules under the Modular Design System project.

Report Organization

The first chapter of this report is a brief overview of the capabilities of SEDAR. Each of the remaining chapters describes how various components of SEDAR may be reused for future research projects. In order of largest component to smallest component they are:

1. *The expert critiquing shell* may be adapted for use in other domains besides flat and low-slope roof design. The extent of shell reuse for a domain depends on several attributes of the domain. For example, shell reuse for other architectural domains maximizes the shell reuse due to their similarities to the roof domain. Other domains may require more developer adaptation. This part of the shell is written in Goldworks III.

2. *The flat and low-slope roof knowledge base* is a partial implementation of the constructibility review criteria established in East et al. (1995). Besides its use in SEDAR, this knowledge base may also be used for other applications for the flat and low-slope roof domain. The knowledge base is written in Goldworks III rule syntax.

3. *A set of two-dimensional (2-D) geometric reasoning functions* were implemented for the expert critiquing shell, and may be used in other architectural or spatial reasoning applications.

4. *A set of Autolisp functions for information display* were also developed for the user interface of SEDAR, which was an augmented version of AutoCAD. Several of these functions may be of general interest and are reported here.

The appendices to this report contain indices of functions, rules, and rule sets for the reusable code, and information about the organization of the code.

2 SEDAR Overview

The SEDAR System helps roof designers by providing critiques and simple suggestions as the roof design progresses. By providing feedback as design decisions are made, errors may be prevented or detected early in the design process, thereby reducing or eliminating the need for extensive redesign due to these errors. SEDAR assists reviewers in checking the correctness of a design by using review knowledge stored in its knowledge base. Because the process of design review is inherently a time-consuming and resource-constrained process, SEDAR will help reviewers by providing consistent and comprehensive automated reviews of the roof design. Use of SEDAR in the existing roof design and review process will help to reduce premature roof failures caused by poor quality roof designs. Roof failures resulting from errors and misjudgments in design constitute a serious legal threat to architects, contractors, and manufacturers alike (Griffin 1982), and result in high repair and maintenance costs to building owners.

SEDAR focuses the content of its critiques and suggestions through the use of a hierarchical decomposition of the roof design task called the *Designer's Task Model* (DTM). The DTM was created from observations of how experienced roof designers divide the roof design task into interdependent subtasks associated with the layout of functional subsystems, such as the drainage or walkway systems. The DTM is used to track the progress of roof designers flexibly and provides a basis for providing relevant critiques and suggestions at appropriate times in the design process.

A prototype version of SEDAR has been implemented for personal computers running Microsoft Windows using Goldworks III, a LISP-based expert system shell, and AutoCAD, a CAD tool. The results of an evaluation of the system were that users had favorable reviews of the system, that SEDAR helped to reduce the number of design errors, and that the functional decomposition of the DTM matched the users' conception of the roof design task.

Critiquing and Suggestion in SEDAR

Three critiquing strategies and one design suggestion strategy are currently implemented in SEDAR. These strategies (*error prevention*, *error detection*, *design*

review, and *simple design suggestion*) differ in their intent, timing, and intrusiveness. The error prevention, error detection, and design suggestion strategies provide advice as the roof designer creates the roof layout. The design review critiquing strategy is intended for use by reviewers and checks user-specified roof subsystems for review criteria violations. Each of these strategies may be turned on or off by the system user at any time; this level of flexibility is provided because individual users have different backgrounds, support needs, and preferences. The critiquing and design suggestion strategies use a common knowledge base containing flat and low-slope roof constructibility review criteria taken from East et al. (1995). Currently the knowledge base consists solely of condition-action rules; this knowledge representation was chosen because of its similarity to the knowledge expressed in East et al. (1995). Each of the strategies uses the DTM to focus the content of its advice.

The Error Prevention Strategy

The intent of the error prevention critiquing strategy is to prevent errors before they occur. The critiquing strategy shows "off-limits" areas on the existing layout when a user selects a design object (i.e., roof drain, air-handling unit, walkway, etc.) from the system's object palette. For example, the error prevention strategy in Figure 1 shows the designer where not to place the selected masonry chimney design object in the roof field. Cross-hatched areas that show minimum spatial separation between the existing objects on the design and masonry chimneys are shown.

The Error Detection Strategy

The intent of the error detection critiquing strategy is to detect errors as they occur. After the designer places an object in the roof field, the new object is checked for constraint violations using a set of relevant review criteria. The user may then examine any of the graphical-textual constraint violations. Figure 2 shows a constraint violation from placing the masonry chimney object too close to an existing chimney; the minimum distances between the objects are shown as cross-hatched areas, the area of the constraint violation is delineated by a dashed rectangle, and the textual portion of the critique is shown below the drawing area.

The Design Review Strategy

The design review strategy is intended to assist reviewers in the process of checking roof designs according to established review criteria, but during the evaluation of the SEDAR prototype many designers used the design review critiquing strategy to check portions of their roof layouts. After the user selects a roof subsystem to review from a graphical/textual dialog box, the system checks the existing design for all

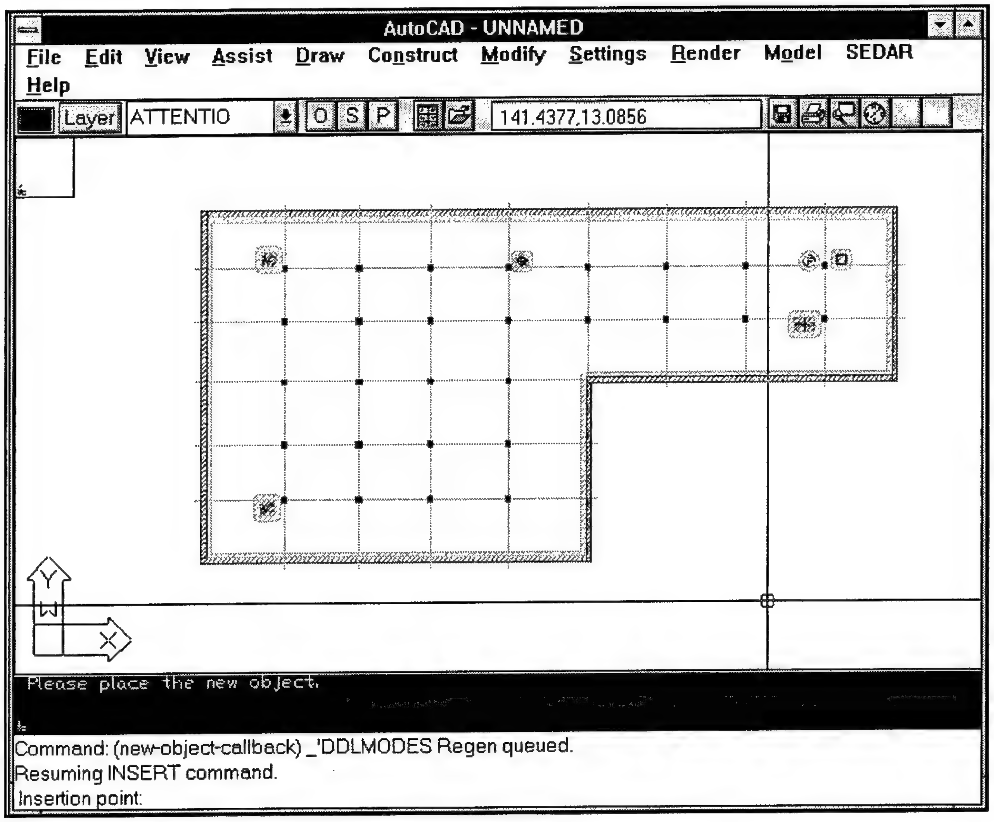

Figure 1. Example of an Error Prevention Critique.

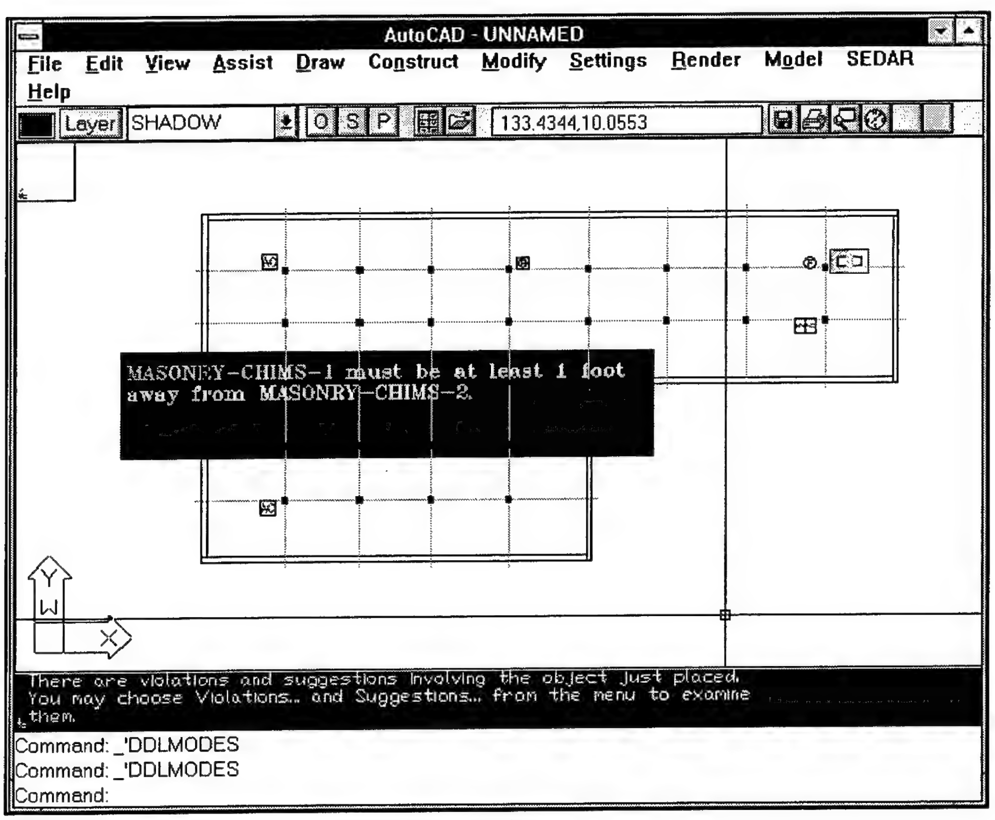

Figure 2. Example of an Error Detection Critique.

constraint violations using rules relevant to the selected subsystem. As in the error detection strategy, the user may examine the resulting graphical-textual critiques. The primary differences between the design review strategy and the error detection strategy are that (1) the design review strategy is user-activated and (2) the design review strategy checks a roof subsystem completely, while the error detection strategy checks for the legality of a single design object.

Simple Design Suggestions

Simple design suggestions are made by the system to guide a user toward a legal configuration of a roof subsystem. For example, the system will suggest the placement of an access hatch on the roof layout if no other means of accessing the roof has already been specified. Figure 3 shows the hatch design suggestion; a hatch is displayed in the upper lefthand corner of the drawing, an arrow is shown connecting the hatch to the roof, and a textual explanation is shown. In addition to these types of suggestions, SEDAR also provides a limited form of design completion. For example, when a saddle-type drainage area is placed in the roof field a roof drain is automatically placed at the low point of the saddle.

System Architecture

The architecture of SEDAR is shown in Figure 4. The *User Interface* is the communication medium between the designer and SEDAR and is an augmented version of AutoCAD. The user may add, delete, or move design objects (i.e., roof drains, air-handling units, walkways, etc.), examine the state of the DTM, view the existing critiques on the design, and turn any of the critiquing strategies on or off. User actions are communicated to the *Critic Management Agent* (CMA), which selects a critiquing strategy to apply and updates the shared data structures on the *Blackboard* (specifically, the DTM and the design representation) to reflect the modification. It then activates the appropriate *Support Strategies* (here the Critiquing and Suggestion Agents), which perform the design analysis according to the selected critiquing strategy, and translates their results into graphical/textual critiques. The critiques are then sent back to the User Interface for display.

The Designer's Task Model and Its Use

A primary contribution of this work to the field of expert critiquing systems is its use of the DTM to focus the content of its advice to issues relevant to the system user. Structurally, the DTM is a subtask hierarchy of the roof design task, consisting of

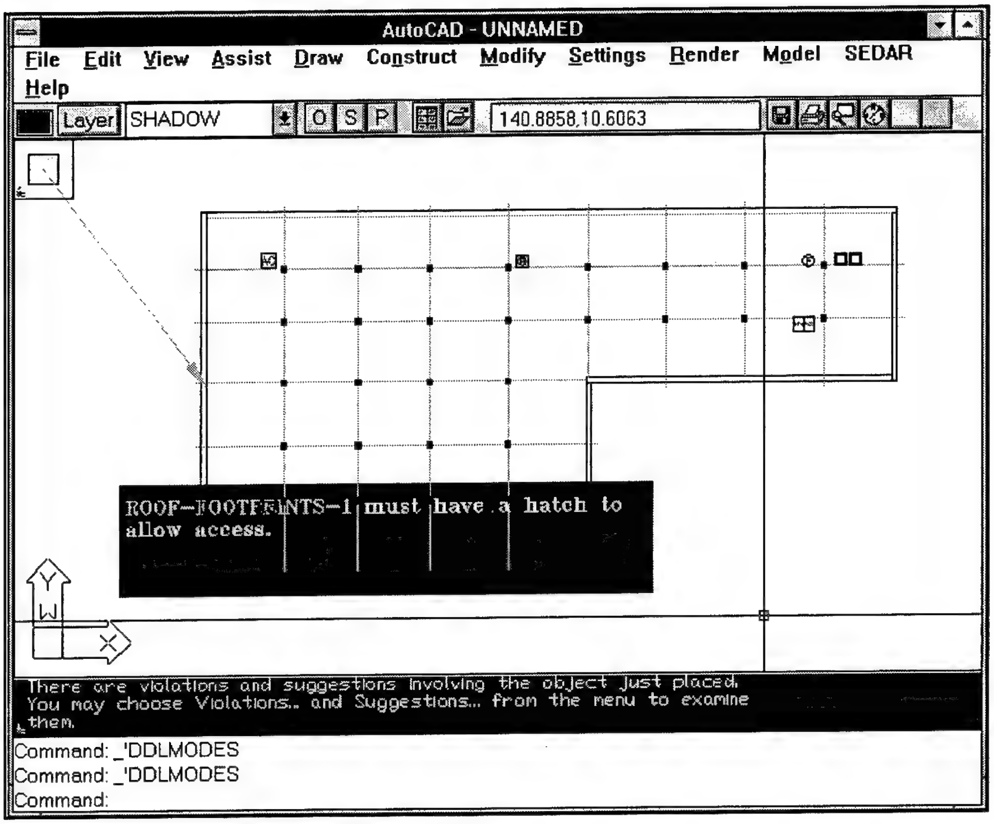

Figure 3. Example of a Design Suggestion.

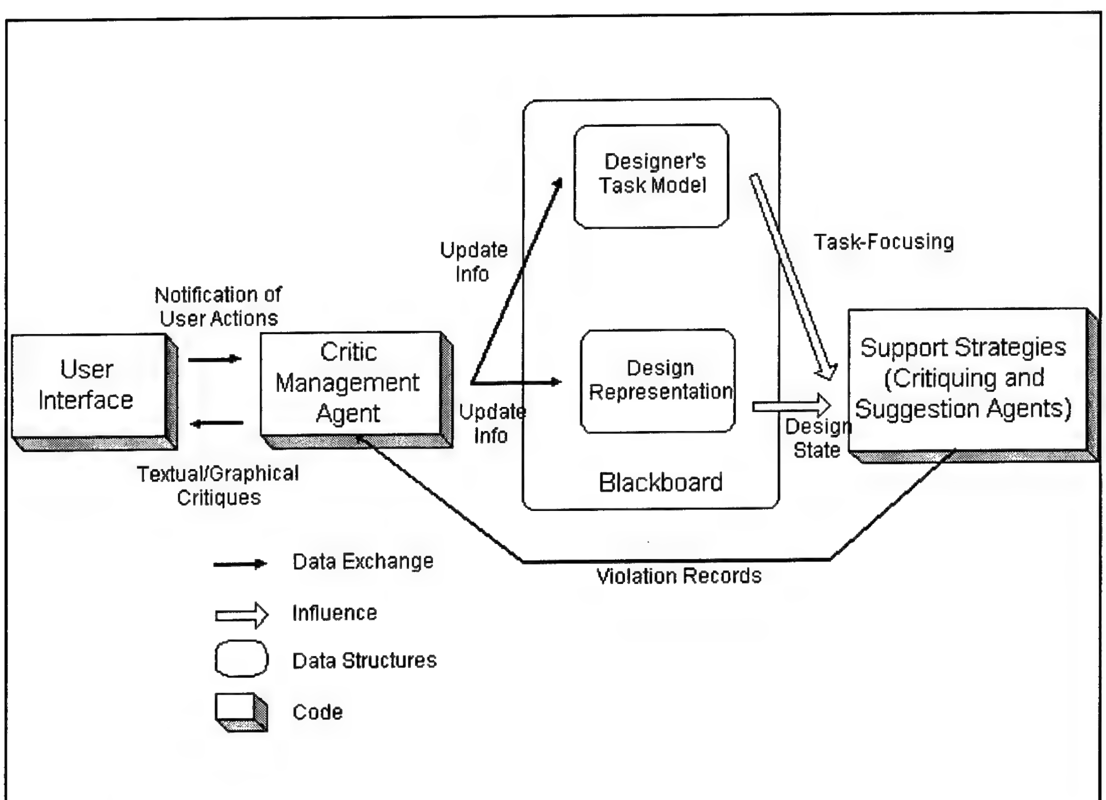

Figure 4. SEDAR architecture.

design tasks that a user may encounter during a roof design. The DTM influences system behavior in three ways: (1) it is used to track the user's progress throughout the design task, (2) the state of the DTM resulting from the tracking process determines the set of review knowledge applied to the existing roof design for each critiquing episode, and (3) the state of the DTM is used to organize the display of advice to the system user.

Structure of the DTM

Figure 5 shows a portion of the DTM; the task at the left, *Roof-Layout*, is the most abstract task. The leaf nodes of the hierarchy (i.e., *Drain-Layout*, *Walkway-Layout*, etc.) represent the design of specific functional subsystems. *Part-of* links, shown as solid lines in Figure 5, describe the task-subtask relationships. *Interferes-with* links represent possible interferences among tasks. Only the interferes-with links related to the *Air-Handler-Layout* task are shown in Figure 5. For example, the *Air-Handler-Layout* and *Walkway-Layout* tasks are related by an interferes-with link because walkways should not overlap air-conditioning units. Each subtask in the DTM is associated with a set of review criteria (in the form of condition-action rules) in the critiquing and suggestion agents specifying acceptable layout conditions.

Use of the DTM

As a designer works on the roof design, the DTM is used to track the designer's focus of attention. Each task in the DTM is either an *inactive*, *active*, or *focus* task. The set of all task states in the DTM forms an *activation pattern*. *Focus* tasks represent SEDAR's interpretation of the user's current focus. Each task is associated with a set of design objects; when a new object is added to the design, all tasks associated with the object and all of the tasks' ancestors in the part-of hierarchy are focus tasks. In Figure 5, the user's selection of a *masonry chimney* object causes the *Chimney-Layout* task and its ancestor, the *Equipment-Layout* task, to become *focus* tasks. *Active* tasks are related to the focus tasks by an interferes-with relation, are subtasks of a task with an interferes-with relation to a focus task, or were focus tasks previously. They represent tasks that not only have been addressed by the user in the past, but also those that should be considered by the user. Finally, *inactive* tasks are those that have not been addressed yet by the user.

During a critiquing episode, SEDAR uses only those review criteria that are linked with focus and active tasks so that the resulting critiques and suggestions are relevant to the user's focus of attention. In Figure 1, for example, all of the "off-limits" areas were generated from rules relevant to masonry chimneys; had the user

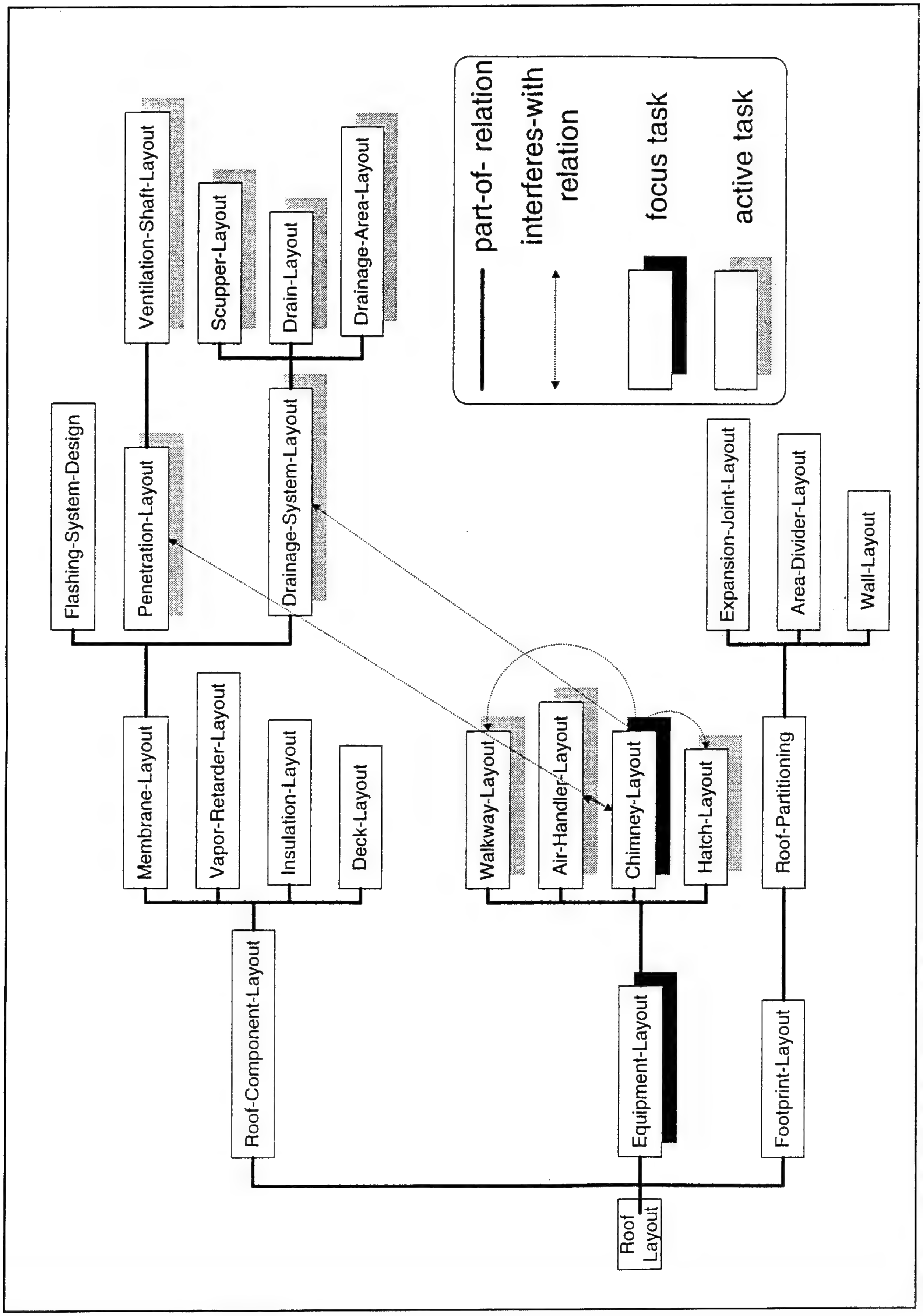

Figure 5. A portion of the Designer's Task Model for flat and low-slope roof design showing interferes-with links to the *Air-Handler-Layout* task.

selected an air-handling unit instead of a chimney a different set of areas would have been shown.

Evaluation and Discussion

A prototype of SEDAR was evaluated in two experiments. The first experiment was a system usability evaluation, which rated the performance of SEDAR along various usability issues. While the full results of this experiment are reported elsewhere (Fu 1994), one outcome of this experiment was an informal verification of the appropriateness of the functional decomposition of roof subsystems of the DTM. The second experiment measured the prototype system's error reduction effectiveness, and showed that designers can use SEDAR to reduce the number of errors in their roof layouts.

The two classes of errors that the system was not able to prevent were optimality issues regarding object placement. The placement of the design object was legal according the review criteria, but the object was placed in a "suboptimal" location. Although the SEDAR prototype does not deal with the optimality of subsystem design, recognizing and advising in these situations was expressed as a need by the system evaluators for future development. Additionally ways are being sought to critique and support designers throughout the design process, from early conceptual design to later detailed design (e.g., Brown and Chandrasekaran 1986).

3 The Expert Critiquing Shell

One goal of the work on SEDAR was to develop an expert critiquing shell that can be adapted for different problem domains. The system is divided into two parts: a "domain-independent" critiquing shell and a knowledge base containing information specific to the flat and low-slope roof layout domain. The first section of this chapter divides the architecture shown in Figure 4 into the shell and knowledge base components. The second section of this chapter describes the data structures and information flow within the expert critiquing shell. The final section of this chapter discusses modification or replacement of the domain-specific knowledge base to allow critiquing in different domains.

No shell is truly completely domain independent, so SEDAR is best used for domains with certain intrinsic qualities. While these domain qualities are not essential, reuse of the shell is maximized in domains that meet many of these qualities. First and foremost, SEDAR is intended for use in domains involving "routine design." Routine design is where the tasks and processes for solving a design task are clearly defined. The DTM of SEDAR is a representation of these tasks and processes, and a consistent model should be elicited from expert designers. Second, SEDAR is best suited for domains in which the solution is constructed from a set of atomic objects. SEDAR's Design Object Hierarchy is a record of the types of these atomic objects. Third, SEDAR contains a library of geometric reasoning functions for use with 2-D spatial layout domains. Chapter 4 discusses this library in greater detail. Researchers who wish to use SEDAR for domains involving 2-D spatial reasoning may use the library as a foundation for their own geometric reasoning routines.

Shell Overview

The architecture shown in Figure 4 provides a component breakdown at a high level of abstraction. The critiquing shell components described in this section have been zipped using Pkzip v.2.04 into the file *sedar-sh.zip*. Of the four major components—the User Interface, the Critic Management Agent, the Blackboard, and the Critiquing Agents—two (the Blackboard and the Critiquing Agents) contain both shell and domain-specific components. The other two components (the User Interface and the CMA) may be reused in their entireties. Two commercial software applications

serve as the base for the four system components: AutoCAD (for the User Interface) and Goldworks III (for the Blackboard, Critiquing Agents, and the Critic Management Agent). The two applications communicate through a DDE interface written by the Concurrent Engineering Team at USACERL.

The Blackboard

The Blackboard contains five subcomponents that are domain-specific. Figure 6 shows a more detailed view of the blackboard and its constituent components. The Blackboard consists of five subcomponents: the DTM, a Requirements Hierarchy, a Materials Hierarchy, a Design Object Hierarchy, and the Design Representation. Each of these subcomponents may be modified to suit other problem domains; only the DTM, the Design Object Hierarchy, and the Design Representation are essential to the operation of the expert critiquing shell.

The Designer's Task Model. The DTM is a hierarchical model of the tasks involved in the problem domain. A DTM for the flat and low-slope roof design domain is shown in Figure 7. As discussed in Chapter 1, the tasks are ordered according to three types of semantic links. Task-subtask links describe the generality ordering between tasks and are shown as heavy black lines in Figure 7. Interferes-with links describe potential interferences between different tasks at the same level of

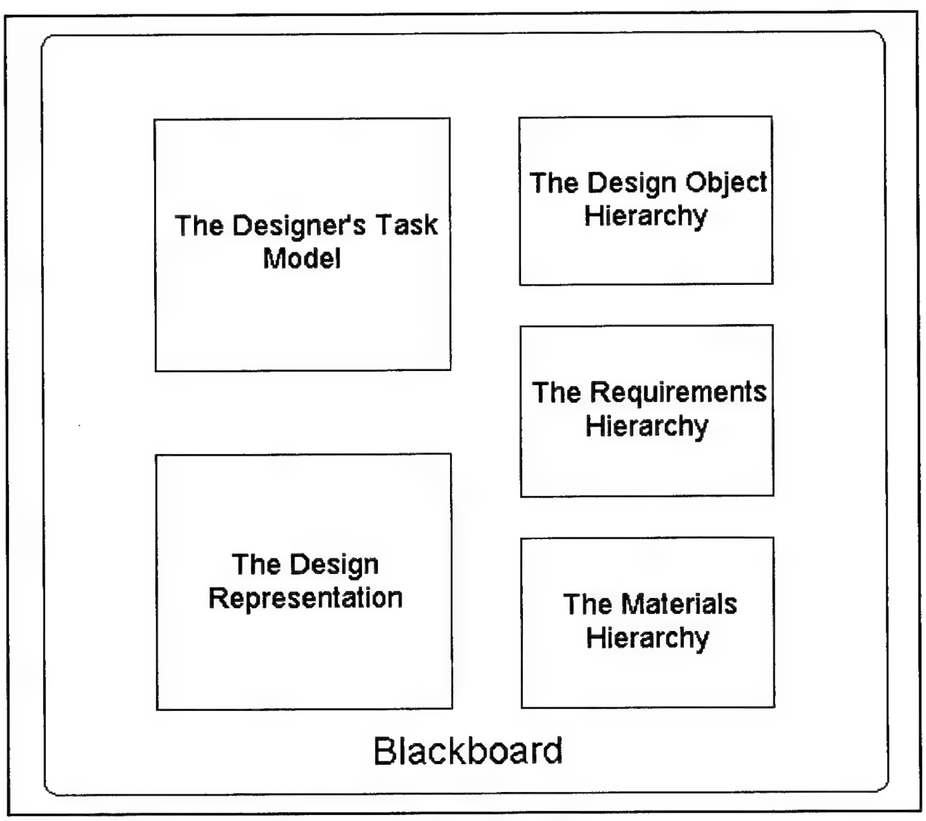

Figure 6. Detailed view of Blackboard component.

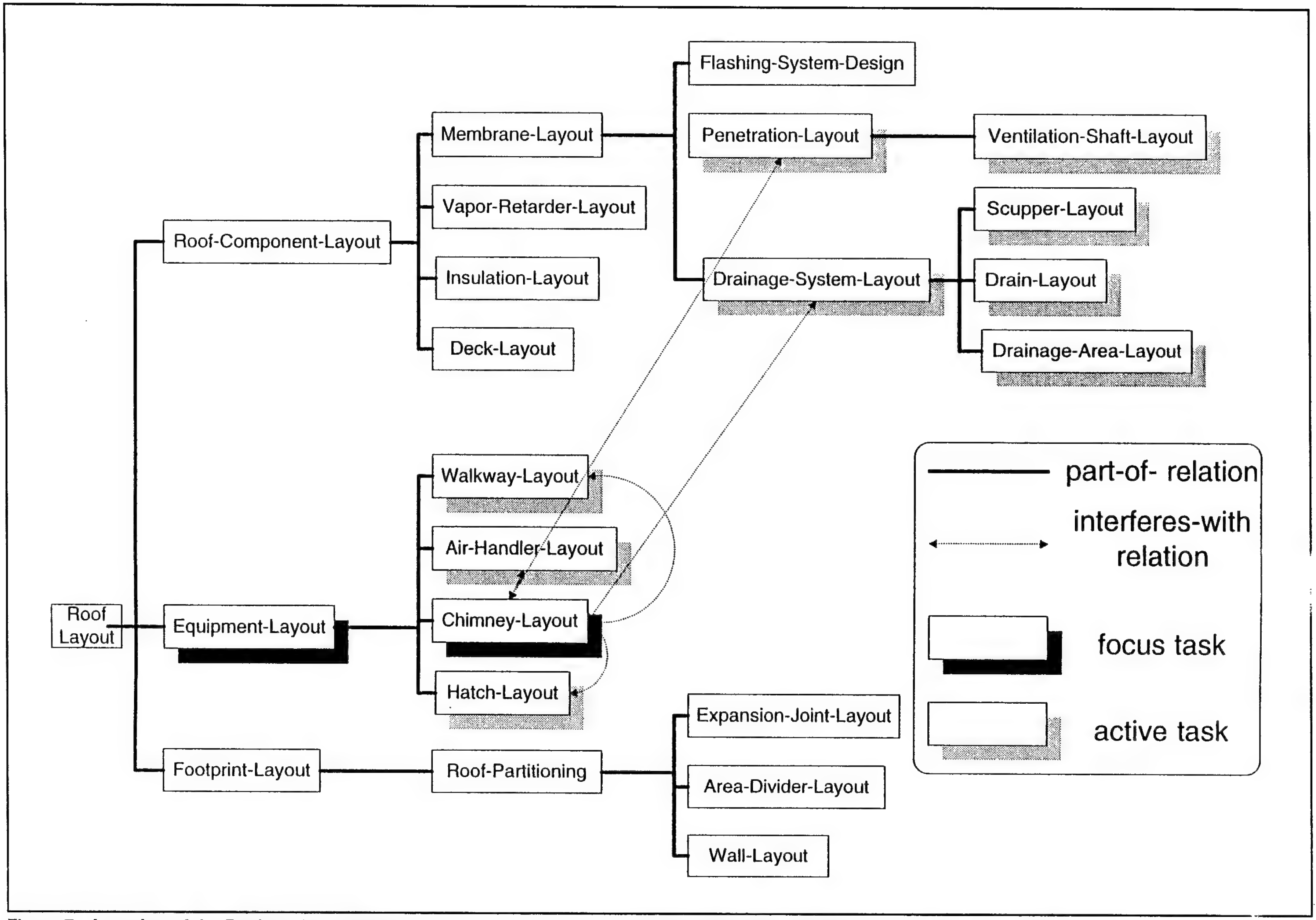

Figure 7. A portion of the Designer's Task Model for flat and low-slope roof design with task-subtask links shown as heavy black lines.

abstraction. Finally, before-task links encode orderings of task execution observed in human expert designers. Only the task-subtask and interferes-with links are used in the current version of SEDAR. The DTM is defined in two files: *frames.lsp*, which contains the task definitions and task-subtask semantic link definitions, and *assert.lsp*, which contains the definitions for the interferes-with and before-task links.

The Requirements Hierarchy. The Requirements Hierarchy is a set of goals or, in the case of design domains, a set of functional requirements that the solution must satisfy. Each goal or functional requirement is linked to a set of rules in the agent knowledge base describing conditions that satisfy (or violate) the requirement. Figure 8 depicts a portion of the Requirements Hierarchy for flat and low-slope roof design. The Requirements Hierarchy is defined in the file *frames.lsp*.

The Materials Hierarchy. Considering the interactions between materials on a roof is also important for quality roof design. For this reason, the Materials Hierarchy contains the various materials used in roofing systems (Figure 9). Individual roof components inherit not only from their parent object types but also from a material; for example, a roof deck may be made of steel, wood, or a type of concrete. Strictly speaking, however, the Materials Hierarchy is not necessary to the operation of the expert critiquing shell. Its use is an artifact of the rules in the flat and low-slope knowledge base rather than of the shell. Like the other hierarchies, the Materials Hierarchy is defined in *frames.lsp*.

The Design Object Hierarchy. The Design Object Hierarchy (Figure 10) is a hierarchical ordering of the different types of objects used to compose the solution in SEDAR. For the flat and low-slope roof design domain, this hierarchy consists of generalized design objects like roof-drains, air-handling units, saddles, and crickets. The design object frames are organized in a part-of hierarchy. The root of the tree is the abstract *physical-system-components* object. All the nonleaf nodes of the hierarchy are used as shell classes and thus are noninstantiable. The leaves of the hierarchy are the instantiable design objects (e.g., *roof-drains*, *ac-units-curbed*, and *attic-vents*). Each design object inherits from its parent in the design object hierarchy, from a set of material frames, and from a shape frame that defines the intrinsic shape of the design object. The shapes of objects are defined in greater detail in the third section of this chapter. The design object frames have slots that describe and structure the attributes associated with the type of design object represented by the frame. When the user selects and places a design object on the drawing, an instance of the generalized design object is made and its slot values filled. Like the other hierarchies, the design object hierarchy is defined in *frames.lsp*.

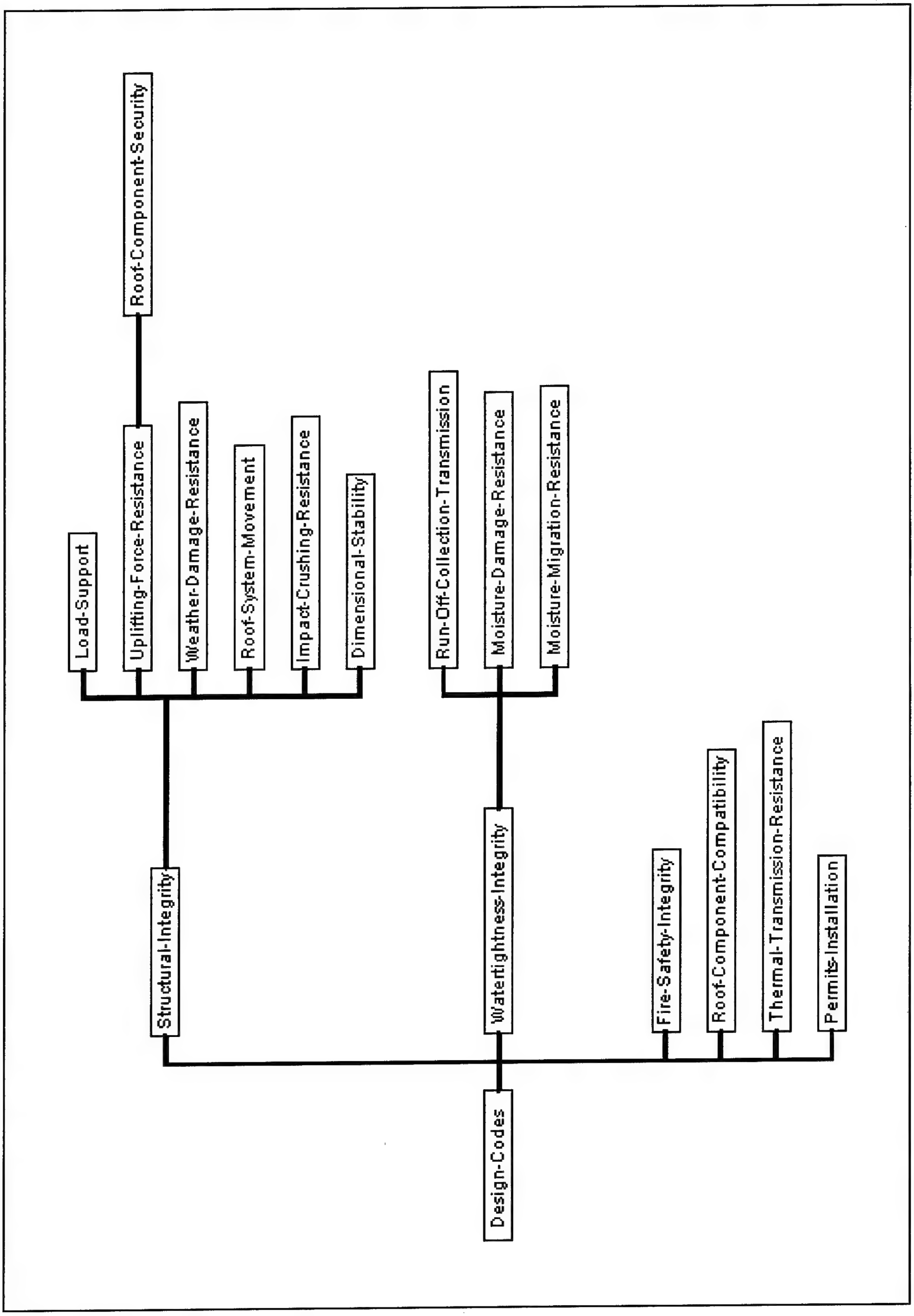

Figure 8. The Requirements Hierarchy.

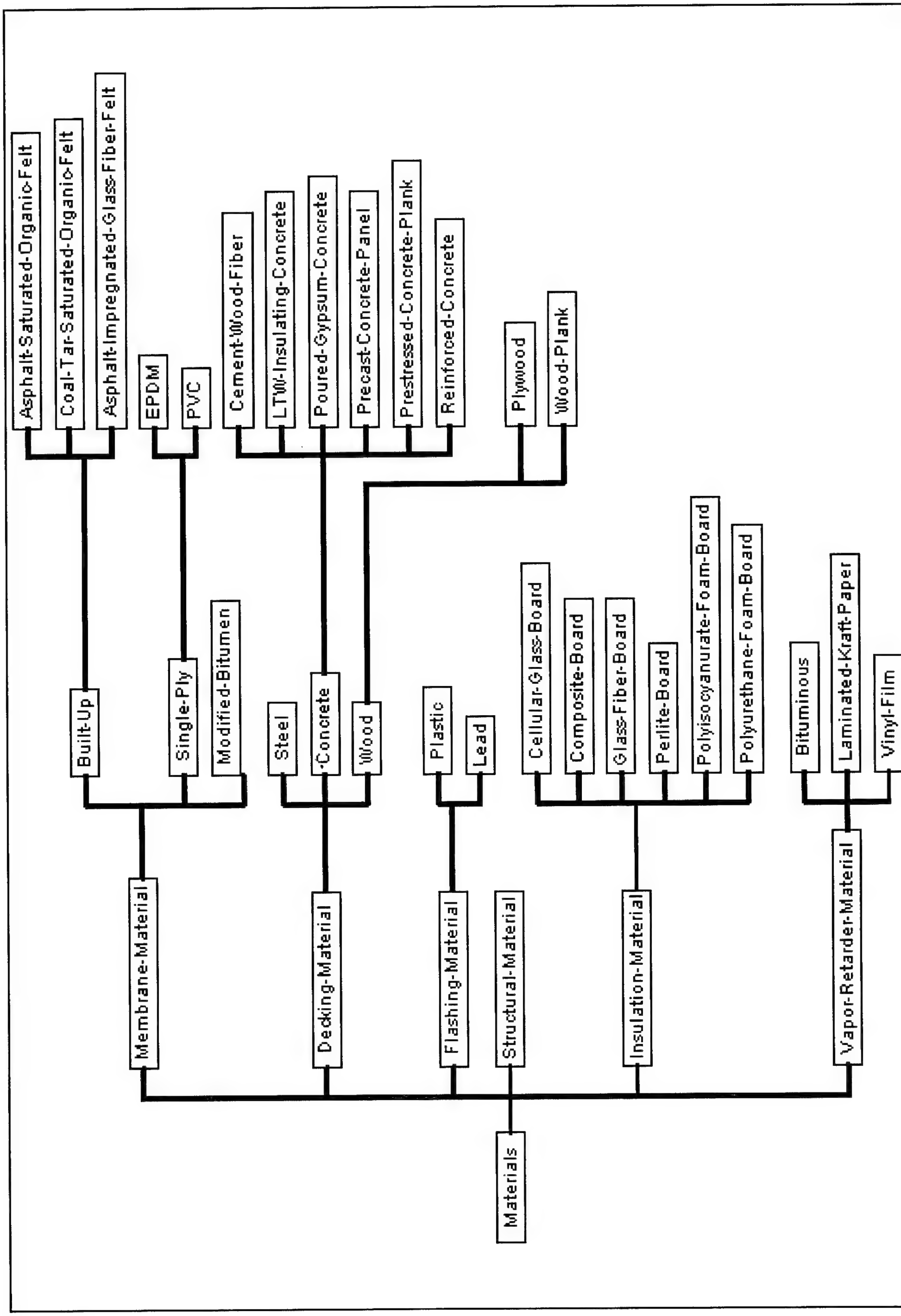

Figure 9. The Materials Hierarchy.

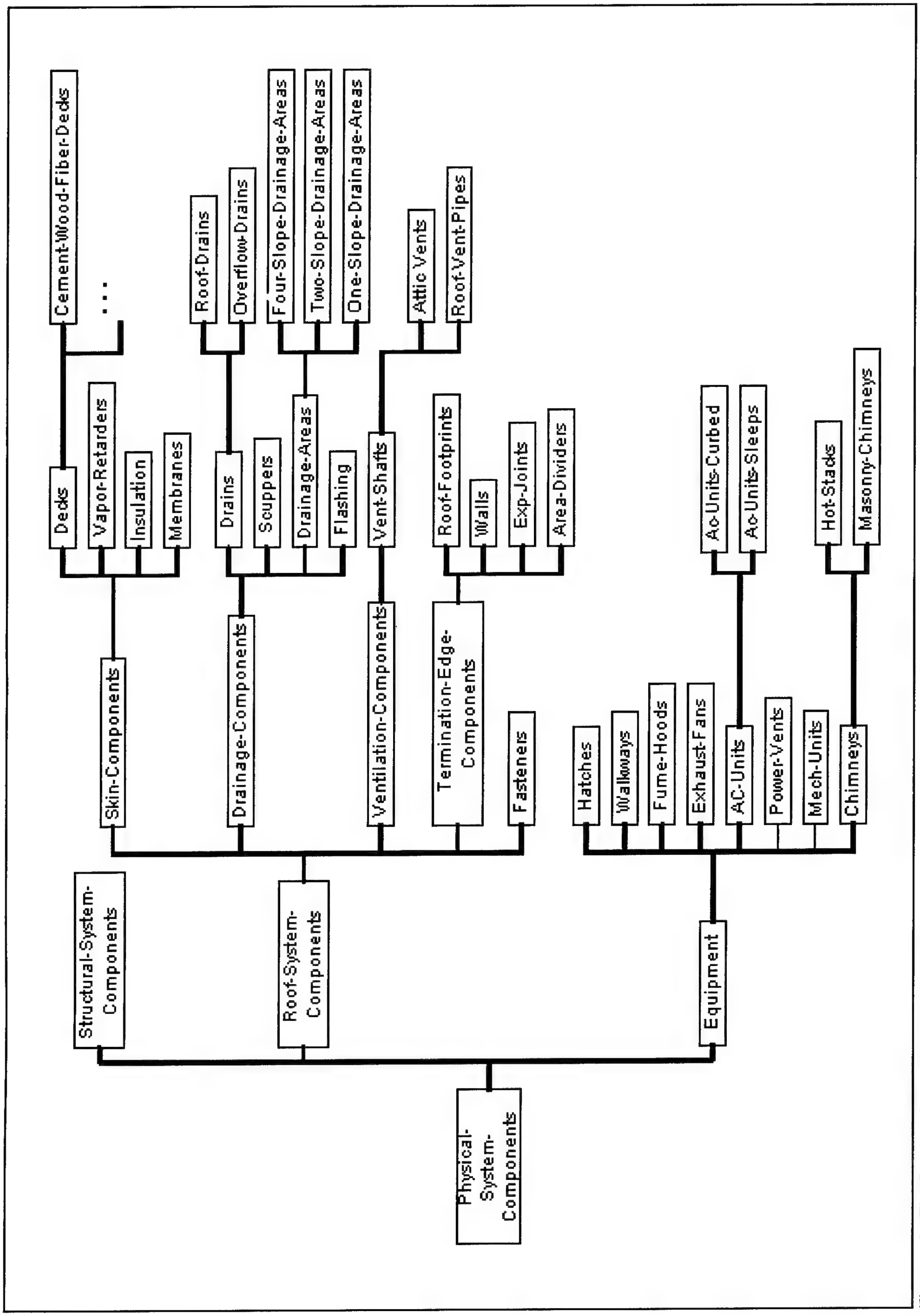

Figure 10. The Design Object Hierarchy.

The Design Representation. The Design Representation consists of object instances and semantic links between the objects. The object instances are created by the human user in the User Interface, and the semantic links are created by a set of Goldworks III rules and LISP functions attached to the generalized object definition in the Design Object Hierarchy. The rules and functions (written in Goldworks III) are automatically fired when an instance of the object is created and are defined in the files *obj-rule.lsp* and *obj-fn.lsp*.

Summary. The reuse of the blackboard is in terms of the conceptual structures required by the expert critiquing system rather than the actual content of those structures, which currently contain information for the flat and low-slope roof design domain. Of these five structures, the DTM, the Design Object Hierarchy, and the Design Representation are the most essential. The DTM is a representation of the problem-solving process of human experts and is used extensively by the Critic Management Agent and the Critiquing Agents. A cognitive task analysis and elicitation of problem-solving structure for human experts in the domain is required for proper definition of the DTM. The Design Object Hierarchy defines the set of objects which, when combined, constitutes a solution for a problem in the domain. The Design Representation encapsulates the critiquing system's representation of the solution being created by the human user. All inferencing and subsequent analysis by the Critiquing Agents is performed on the design representation. The requirements for redefinition of these three subcomponents is discussed in greater detail in the third section of this chapter.

The Critiquing Agents

SEDAR supports three distinct critiquing agents and one design suggestion agent. The critiquing agents are: the error prevention critic, the error detection critic, and the design review critic. The suggestion agent is called the simple design suggestion agent. Each of these agents use rules defined in a central knowledge base—the flat and low-slope roof design knowledge base—for the current implementation of SEDAR. The relationship between the agents and knowledge base is shown in Figure 11. The agents differ in their timing, intrusiveness, and intention for the user. The error prevention critic attempts to steer users away from anticipated error patterns before they have the chance to commit them. The error detection critic complements the error prevention strategy by checking the solution for errors concerning the rules in the flat and low-slope roof design knowledge base. Finally, the design review strategy allows the user to select various solution subcomponents to critique. In the case of roof design, solution subcomponents are roof subsystems like the drainage system design.

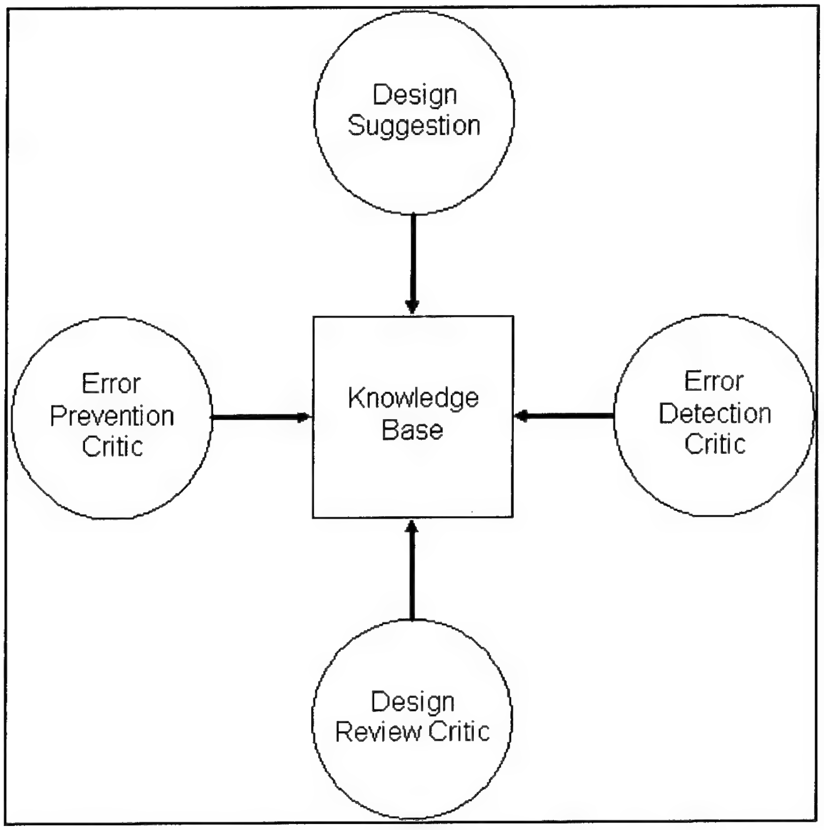

Figure 11. Relationship between critiquing/suggestion agents and the knowledge base.

The critic agents themselves are encoded in the file *cma-main.lsp* and are part of the expert critiquing shell. The knowledge base, comprised of files of Goldworks III rules in the \kb subdirectory under the gcl44\sedar directory, are specific to the roof domain only.

The User Interface

The user interface is an augmented CAD system (AutoCAD™) that allows direct manipulation of both the design and the criticism generated by SEDAR. This part of the system may also be termed as the "front-end" of SEDAR; it is the medium through which the interaction between the human designer and the critiquing system takes place. Furthermore, the user interface constitutes a powerful design environment within which the user may compose a design, control the critiquing system, and view the generated critiques. Figure 12 shows a screen capture of the SEDAR interface of a partially completed roof design and a critique generated by the system. The menu displayed in the figure is the Action Menu from which the user selects operations to perform on the design. The interface is divided into the Design, Suggestion, and Dialog windows. The large area in Figure 12 containing the top-down view of the roof design is the Design Window. Critiques generated by the system are

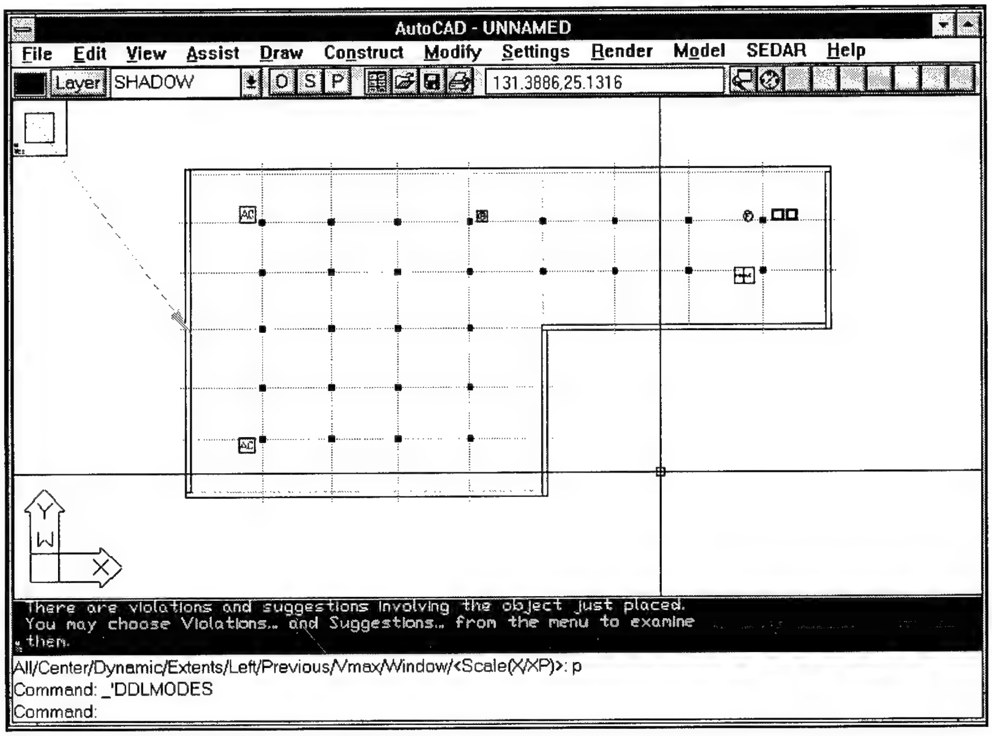

Figure 12. The SEDAR user interface.

displayed here. The small window at the upper left corner of the Design Window is the Suggestion Window. Critiques that involve design suggestions use this window in addition to the Design Window. In Figure 12, the current suggestion is that a hatch be placed on the design to allow access to the roof from below. The suggested hatch object is shown in the Suggestion Window. Finally, the Dialog Window at the bottom of the Design Window displays textual information, including prompts and the textual portions of critiques.

The code for the user interface resides in the files under the \sedar directory. Besides *.lsp files, files are available for the design objects and menus used in the user interface.

The Critic Management Agent

The CMA is the control unit of the expert critiquing system. It receives and interprets descriptions of user actions from the user interface, updates the representations on the blackboard, selects which critiquing strategies to apply, and activates the proper critic agents. The CMA selects from one of four agents: three critiquing agents (error prevention, error detection, and design review) and a simple design suggestion agent. After the critiquing process is finished, the CMA gathers the generated critiques, translates them into critique display descriptions that the user interface understands, and sends them to the user interface. The CMA operates in

a loop called the iterative critiquing cycle, which is described in the second part of this chapter. The main file containing the CMA Lisp functions is *cma-main.lsp*.

System Operation and Information Flow Across Components

System Operation: The Iterative Critiquing Cycle

SEDAR uses the *iterative critiquing cycle*, which forms the framework in which all SEDAR's actions are organized. The cycle is maintained by the CMA and has six stages, as shown in Figure 13. Each phase of the cycle is annotated with the components that are involved in its completion. This section describes the iterative critiquing cycle at a high level.

Stage 1: Receive User Input. The user selects an action to perform, such as adding, moving, deleting, or resizing existing design objects, or selecting goals for review. Depending on the selected action, the interface may query the user for additional information. The interface then sends a message to the critic management agent notifying it of the user's action and providing information that the critic management agent will need.

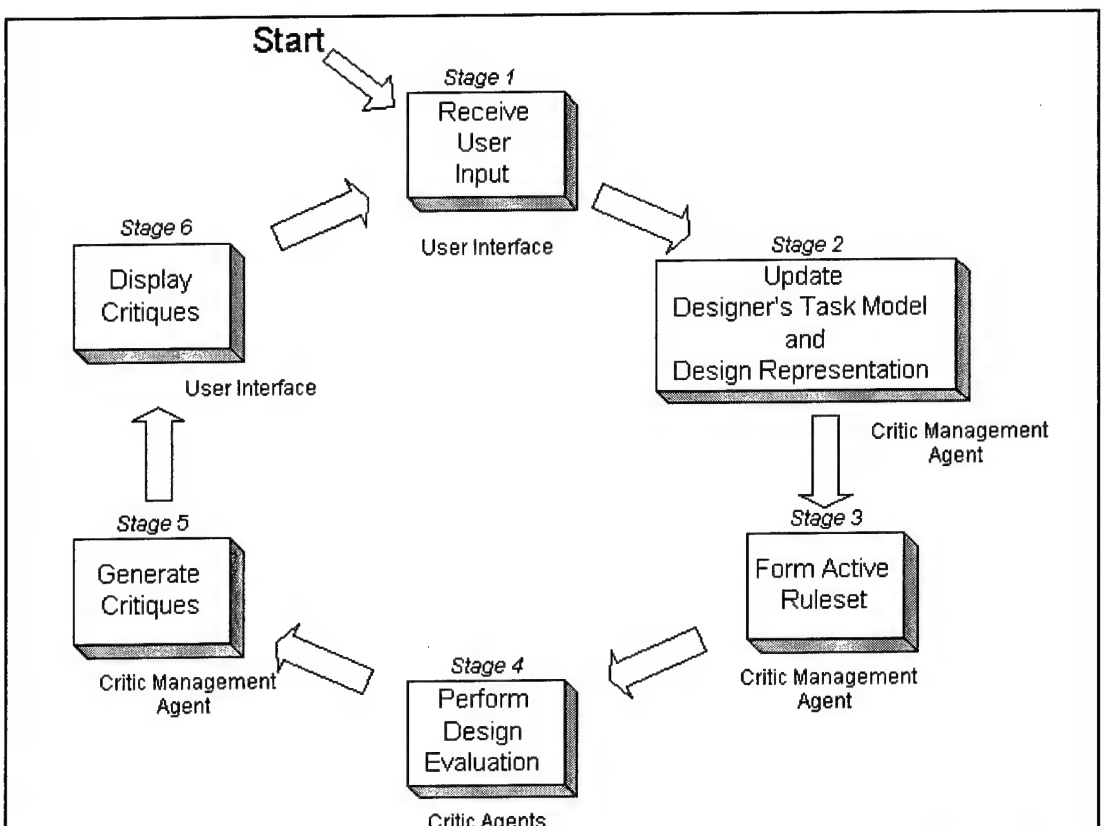

Figure 13. The iterative critiquing cycle.

Stage 2: Update the DTM and the Design Representation. Upon receiving the message from the user interface, the first task of the CMA is to update the DTM. Specifically, the CMA uses the previous DTM activation pattern and the current user action to decide which tasks in the DTM to make focus or active for the current critiquing session. This method of task activation allows for greater flexibility in the interaction between the user and the system. For example, some users may like to operate on multiple tasks simultaneously. While SEDAR does not actively enforce a particular ordering of satisfaction of its goals, it does have the capability to provide suggestions as to which tasks should be dealt with before or concurrently with the current set of tasks.

The second task for the CMA is to modify the design representation according to the user action. For example, the CMA may make a "temporary" object or a "real" object. If a "real" object is instantiated on the design representation, additional semantic links may also be created at this time to link the new design object to the previously existing objects.

Finally, the critiquing strategy is selected. Depending on the user's actions, the CMA selects from the error prevention, error correction, and design review critiquing strategies. The method of selection is static in nature.

Stage 3: Forming the Active Rulesets. During this stage, the set of design codes to be applied for the current critiquing cycle is created. All design codes are taken from the constructibility knowledge base. Only the rules linked to tasks with focus and active activations in the DTM are included in this set.

The CMA may then modify the rules in the active ruleset, depending on the critiquing strategy. This modification is done to focus the activity of the next stage on relevant objects and to improve efficiency.

Stage 4: Perform the Design Evaluation. The active set of design rules is then applied to the existing design on the blackboard. Each design code rule is a condition-action rule taken from a published handbook of low-slope roofing specifications (NRCA 1985). If the preconditions of a design code rule match a set of features in the design representation, a *design code violation* is specified with respect to those features. In every critiquing cycle, only a subset of the knowledge base of rules is applied to the design. This improves the efficiency of the design evaluation stage and, more importantly, ensures that the set of critiques and suggestions provided by the system is appropriate given the state of the design and is relevant to the user's current focus.

Stage 5: Generate Critiques. In this stage, the violation data from the previous stage are collected by the CMA and are used to generate the critiques seen by the user. An overview of this important element of the process is described here.

Critiques have separate graphical and textual portions. The CMA uses design-code specific information to create a graphical critique component in a graphical language understood by the user interface. In particular, the violation data is used to instantiate unbound variables in a stored graphical component template. The textual component generation process follows the graphical component generation. An explanation template containing unbound variables is instantiated with the violation data.

During this stage the critiques are also arranged in order of display to the user. The DTM plays an important role here; the critiques most relevant to the current focus of the user have greater priority over the rest of the critiques, which are arranged according to a serialization of the before-task partial task ordering.

Stage 6: Display Critiques. Depending on the critiquing strategy, the user interface may show the graphical/textual critiques immediately or by user request. The error prevention strategy displays all of the generated critiques on the drawing without user prompting. The error correction and design review strategies, however, simply display a notification to the user that critiques were found.

After this stage, the system loops back to Stage 1 and waits for a user action on the design. The process terminates when the user exits from SEDAR.

Known Problems. During the development of the expert critiquing system, the distinction between the iterative critiquing process and the individual critic agents was blurred due to pragmatic concerns. As a result, the task of carrying out the iterative critiquing process is split between code for the CMA and code for the individual Critic Agents. More specifically, Stage 5, which is conceptually the responsibility of the CMA, is actually performed by the Critic Agents themselves. This problem will be dealt with in future releases of the system.

Detailed System Operation and Information Flow Across Stages

Although a complete description of the system behavior is outside the scope of this report, an attempt will be made to provide the reader with a more detailed account of system activities. This account is, as in the previous section, defined in terms of the iterative critiquing cycle described at a high level above. Particular attention is given to the interactions between the expert critiquing shell and the domain-dependent portions of the system described in the first section of this chapter.

Stage 1: Receive User Input. When the user selects an entry from the Action Menu, an appropriate callback function is activated. For example, suppose the user selects **New Object...** from the Action Menu. The new-object-callback function calls a function that activates the New Object Dialog box. After the user selects a type of object, the new-object-callback function creates a unique identifier for the object and calls the CMA, passing along the user request and additional information about the object. This is accomplished by using a LISP function call to *call-gcl*. The parameters to *call-gcl* are eventually evaluated by Goldworks; hence, to activate the CMA, the initial component of the parameter to *call-gcl* is an s-expression containing a call to the top-level function of the CMA. The new-object-callback function then waits for the value returned from the CMA.

Information Transfer Between Stage 1 (User Interface) and Stage 2 (Critic Management Agent). As noted in the previous paragraph, the *call-gcl* function is called with an s-expression corresponding to an invocation of the top-level CMA function, *ac-message*. The parameters passed to the CMA within this s-expression depend on the type of request made in the user interface. The complete set of requests supported by the CMA is described in the comment for the ac-message function in the file *cma-main.lsp*. In this case, the user has requested a new object placement, and the s-expression resulting in the call to *ac-message* is:

(ac-message <query-id> “user-select-object” (<object-type> <object-id>)).

<query-id> is a number maintained by the system to keep track of requests and information generated by the requests on the blackboard. The string “user-select-object” identifies the type of user request. Since the user has just requested a new object (and has not yet placed the object), the only object information available is the <object-type> (e.g. roof-drains, ac-units-curbed) and the unique identifier of the object, <object-id>.

Stage 2: Update DTM and Design Representation. Upon receiving the request the *ac-message* function calls the appropriate LISP function to carry out the user request. In general, the names of these functions correspond to the user request; for example, the function called by *ac-message* given the user-select-object request is *do-select-object*.

The *do-select-object* function embodies the activities of the error prevention critic agent. It first updates the DTM according to the user request and the type of object selected by the user. All tasks directly related to the new object type are asserted as focus tasks. All focus tasks from the previous iteration and all tasks related to the new focus tasks by an interferes-with relation are asserted as active tasks. The

activations, which are asserted into the working memory, look something like the following:

(focus-task <query-id> <task-name>)
and
(active-task <query-id> <task-name> <activation-type>).

The set of these assertions record the state of the DTM for the current request. Previous focus-task and active-task assertions are not retracted from the working memory and are used as a history of DTM activations.

After updating the DTM, the *do-select-object* function makes a *shadow instance* of the selected object type in the design representation. A shadow instance is simply an instantiation of the object type without slot information (since the location of the object is not known). The shadow assertion is made so that the rules inside the knowledge base can be defined with consistent semantics. Conceptually, each rule in the knowledge base checks on a relationship between two or more design objects. Thus a shadow object is required in this case.

Stage 3: Form Active Ruleset. After performing the updates of the DTM and the design representation, the *do-select-object* function then forms the set of active rules to apply for the critiquing episode. Since this stage is within the same function as the previous stage, no information is explicitly transferred between system components. The process of forming the active ruleset is embodied in two functions: *get-active-rules*, which collects the set of rules from the knowledge base based on the state of the DTM, and *make-object-select-ruleset*, which modifies the selected rules to work with the error prevention critic. The *get-active-rules* function simply generates a union of the rules associated with focus and active DTM tasks. The set is returned as a list of rule names to *make-object-select-ruleset*. *Make-object-select-ruleset* then forms the set of active rules by modifying each rule in the selected set. Each rule is specialized to apply to the new shadow object so that the constraint information generated by the application of these rules is pertinent to not only the current state of the DTM but also the newly selected object type. After modifying the rules, the *make-object-select-ruleset* function defines a new rule set in Goldworks III containing the modified rules and deactivates it in preparation for the next stage.

Stage 4: Perform Design Evaluation. The new rule set is activated and allowed to forward chain to completion on the design representation. The result of the Perform Design Evaluation stage for the error prevention critic is a set of *check-condition*

assertions made by the active rules. These check-condition assertions have the form:

(check-condition <notification-id> <query-id> <rule-name> <variable-binding-list>).

The <notification-id> is a unique identifier for the check-condition assertion. The <query-id> is as previously defined. The <rule-name> represents the rule that created the check-condition assertion. Finally, the <variable-binding-list> records the bindings of rule variables to objects in the design representation. Since the rules were originally modified to apply to the shadow object in Stage 4, one of the elements of the <variable-binding-list> is always a binding involving the shadow object. For other critic agents this will not be the case.

Duals of check-condition assertions are removed during this stage. An example of duals is:

(check-condition CONST-AREA-1 1 RULE-6 ((“?drain-1” DRAIN-1) (“?drain-2”
DRAIN-2)))

and

(check-condition CONST-AREA-2 1 RULE-6 ((“?drain-1” DRAIN-2) (“?drain-2”
DRAIN-1))).

The primary difference between the two check-condition assertions is that the bindings of design objects to rule variables are reversed. The second check-condition assertion is eliminated.

Another issue is that of assertions resulting from rules of different *levels*. Rules in the knowledge base are separated into three categories: *physical-level*, *specification-level*, and *preference* rules. Physical-level rules check for physical impossibilities (e.g., placing a drain outside the roof field). Although these are “common-sense” rules, they of all rules are the most important. Specification-level rules are those specified in published code books. For the case of flat and low-slope roof design, specification-level rules were taken from the work (East et al. 1995) and other handbook sources (NRCA 1985). An example of a specification-level rule would be: “Drains should be placed at least 1 foot away from other drains.” Finally, preference-level rules encode individual designers’ preferences. A roof designer may like to place overflow drains close to roof drains to alleviate ponding from drains clogged by debris. Another designer may choose to use scuppers cut through the parapet wall surrounding the roof field for overflow drainage instead. The check-

condition assertions resulting from physical-level rules are given preference over specification-level rules, which are in turn given preference over preference-level rules. For the error prevention critic, all check-condition assertions are kept and passed to the next phase, but for the error detection and design review critics only the constraint violations (for a particular object) of the highest level are kept and passed to the next phase.

Stage 5: Generate Critiques. After the active rulesets are allowed to forward chain in Stage 4, the resulting check-condition assertions are collected and turned into graphical/textual critiques. Each rule has both a textual and graphical template which is used to generate the critique. The templates reference variables used within the rule. For example, RULE-21, which checks to see if a piece of equipment is accessible via walkways from the roof access mechanism, has the following two critique templates:

Textual Critique Template:
("There should be a walkway from " "?e1" " to " "?e2" ".")

Graphical Critique Template:
(MULTIPLE-DRAW
(DRAW-BOUNDARY-AREA "?e1" UNKNOWN INTERIOR 0)
(DRAW-BOUNDARY-AREA "?e2" RECTANGULAR-
COMPOSITION INTERIOR 0)).

The textual critique template consists of a list of strings. Each string may either be text (e.g., "There should be a walkway from" and ".") or a variable (e.g., "?e1"). Variable strings have a ? as the first character, and refer to variables within the body of the rule. The graphical critique template consists of a recursive list of graphical commands for the User Interface, and also contains strings corresponding to variables in the rule body. Critique generation for each check-condition assertion from Stage 4 is a replacement of the variables within the templates with the variable bindings in the <variable-binding-list> portion of the check-condition assertion.

The generated textual and graphical portions of the critique are prepended with information about the source of the critique:

(<constraint-area-name> <rule-name> <task-name> <violation-level> <graphical-critique-portion> <textual-critique-portion>).

The <constraint-area-name> is taken from the check-condition assertion and serves as the unique identifier of the critique in both the expert critiquing shell and the

user interface. <rule-name> is the name of the rule that generated the critique. <task-name> is the name of the focus or active task associated with the rule. <violation-level> declares the level of the rule (physical-level, specification-level, or preference). Finally, <graphical-critique-portion> and <textual-critique-portion> are the components of the critique described previously. An example of an instance of this construct would be:

```
(   CONST-AREA-1
    RULE-21
    WALKWAY-LAYOUT
    SPECIFICATION-LEVEL
    (MULTIPLE-DRAW
        (DRAW-BOUNDARY-AREA AC-UNITS-1 UNKNOWN INTERIOR 0)
        (DRAW-BOUNDARY-AREA HATCHES-2 RECTANGULAR-
            COMPOSITION INTERIOR 0))
    ("There should be a walkway from AC-UNITS-1 to HATCHES-2.")
).
```

Information Transfer Between Stage 5 (CMA) and Stage 6 (User Interface). The information passed back to the waiting user interface component varies according to the user requested action. In the case of a user-select-object action, the do-select-object function returns two components in a list: the set of constraint areas resulting from Stage 5 and the set of current DTM activations. Both of these sets are represented as lists; thus the whole return value has the following form:

```
(
    (<constraint-area-1> <constraint-area-2> <constraint-area-3> ...)
    (<task-activation-1> <task-activation-2> <task-activation-3> ...)
).
```

The information passed back to the user interface differs according to the user request. All CMA functions pertaining to user requests may be found in the file *cma-main.lsp*.

Stage 6: Display Critiques. After the CMA returns the list of constraint areas and task activations to AutoCAD, the original new-object-callback function takes the set of constraint areas and proceeds from the original call to Goldworks. The display of the critiques is handled differently depending on which critic agent generated the critiques. Since the goal of the error prevention critic is to display "off-limits" situations to prevent errors from occurring, all the generated critiques are displayed immediately in the drawing area by iterating over the *draw-constraint-action*

function. In the case of the error detection critic, only a textual message notifying the user of the constraint violations are displayed; the user may then page through the critiques using additional dialog boxes.

System Reuse

This final section of the chapter describes what domain-specific components are required to use the SEDAR expert critiquing shell in other domains. In the previous section, we have discussed the necessary domain-specific components of the Blackboard (the DTM, the Design Object Hierarchy, and the Design Representation) and of the Critiquing Agents (the central knowledge base used by the critiquing and suggestion agents).

Adapting the Blackboard Components

The Designer's Task Model. The DTM should be created from protocol analyses with human experts in the problem domain. Combining expertise (e.g., forming a union of the commonly encountered tasks) is allowed because the DTM is used to track rather than guide user behavior. As such, the set of tasks in the DTM may be a superset of the tasks of any individual designer. One pitfall that must be accounted for is the possible existence of multiple fundamentally different task breakdowns for the problem domain; in this case, additional functionality to represent, select, and update multiple DTMs (each of which represents one of the different task breakdowns) is needed.

The DTM for a problem domain is defined in two files: *frames.lsp* and *assert.lsp*. The *frames.lsp* file contains Goldworks III frame definitions that represent the task-subtask semantic links among the tasks. An example frame definition is:

```
(DEFINE-FRAME DRAIN-LAYOUT
   (:IS DRAINAGE-SYSTEM-LAYOUT)).
```

This statement is a definition of the *Drain-Layout* task, whose parent is the *Drainage-System-Layout* task. The *assert.lsp* file contains additional information about the DTM, including lookup knowledge about the subtree structure of the DTM, for example:

```
(goal-subtree-assoc architectural equipment-layout
   (equipment-layout air-handler-layout walkway-layout chimney-layout)).
```

This goal-subtree-assoc assertion lists all of the tasks in the subtree of the *Equipment-Layout* task, including *Equipment-Layout* itself. The interferes-with semantic links are encoded as *possible-goal-interference* assertions:

(possible-goal-interference architectural equipment-layout ventilation-shaft-layout).

The possible-goal-interference assertion specifies a pair of possibly interfering tasks. In the example, the tasks are *Equipment-Layout* and *Ventilation-Shaft-Layout*; the layout of mechanical equipment on the roof (e.g., air-handling-units) may interfere with the layout of ventilation shafts.

Each task has a set of *trigger objects*. When the user selects a new object for the solution, all tasks in the DTM with a trigger object of the selected object type are activated as focus tasks. A task may have more than one trigger object. An example of a pairwise goal-object-assoc assertion defining a walkway as a trigger object for the Walkway-Layout task is:

(goal-object-assoc architectural walkway-layout walkways).

Finally, each task in the DTM is associated with a set of rules from the knowledge base for the Critiquing Agents. The union of the set of rules associated with focus and active tasks for a critiquing episode constitutes the selected set of rules for that episode. Rule 21 checks whether each piece of equipment on the roof is accessible via a walkway from the roof access mechanism. Because air-handling-units are considered equipment, the following assertion exists:

(rule-goal-assoc architectural rule21 air-handler-layout).

The Design Object Hierarchy. Like the DTM, the Design Object Hierarchy is arranged along class-subclass relations. The objects in the Design Object Hierarchy define the basic building blocks of solutions in the problem domain. Each "node" in the hierarchy constitutes a "class" of objects. When the user selects a type of object to include within the solution, an instance of the class of the selected object is created.

Each design object class has two types of slots: inherited and unique. In SEDAR, each design object class has two types of inherited slots: slots that pertain to the shape of the object and slots that pertain to the material of the object. For reuse of the geometric libraries written for the flat and low-slope roof design version of SEDAR, the shape of the object must either be a Circle or a Rectangular-Composition. All objects within the flat and low-slope roof design version of SEDAR have

one of these two shapes. These objects are described at length in Chapter 5, which discusses the reuse of the geometric reasoning libraries. The slots that pertain to the material of the object are also domain-specific and may not be needed for other problem domains. In general, design objects may have any number of inherited slots. Besides the inherited slots, each class of design object may have its own set of unique slots that describe features specific to the class. An example of the set of unique slots for the class of expansion joints on a roof is:

```
(DEFINE-FRAME Exp-joints
  (:IS (TERMINATION-EDGE-COMPONENTS RECTANGULAR-COMPOSITION))
  (ENDPOINT1 :DEFAULT-VALUES (NIL))
  (ENDPOINT2 :DEFAULT-VALUES (NIL))
  (WIDTH :CONSTRAINTS (:LISP-TYPE NUMBER))
  (user-modifiable-slots :default-values ((endpoint1 endpoint2 width)))
  (activate-when-created-ruleset :default-values (expansion-joint-ruleset))
  (activate-when-created-functions:default-values((complete-expansion-joint-slots)))).
```

The name of the class is Exp-joints. The second line defines the direct ancestors of the Exp-joints class; it is a form of Termination-Edge-Component and inherits shape slots from the Rectangular-composition class of shapes. The Exp-joints class has three unique slots: Endpoint1, Endpoint2, and Width. The final three lines of the Exp-joints definition contain more information about the class. The User-modifiable-slots field contains a list of the slots that may be altered by the user. The Activate-when-created-ruleset and Activate-when-created-functions fields contain lists of rulesets and/or functions that act when a new instance of the object class is created. For example, when a new expansion joint is created by the user, the *expansion-joint-ruleset* will fire, and the *complete-expansion-joint-slots* LISP function will be called with the name of the new expansion joint. These rulesets and functions are located in the files *obj-rule.lsp* and *obj-fn.lsp*.

Finally, each new object type that is created should result in new assertions in *assert.lsp*:

- *goal-object-assoc* assertions that link tasks to their trigger objects
- *rule-object-assoc* assertions that link rules in the knowledge base to object classes.

The Design Representation. The design representation consists of a set of object instances and a set of semantic links among the object instances. These two sets are highly domain-dependent and are closely linked to the rules in the knowledge base; the rules in the knowledge base may look for certain types of semantic links between

object instances. The semantic links may be general spatial relation links (e.g. *distance-greater-than, area-enclosed-within*) or they may be more specific. A set of general spatial relation links are provided by the geometric reasoning library discussed in Chapter 5. Domain-dependent semantic links are often defined in the files *obj-rule.lsp* and *obj-fn.lsp*, which contain the rulesets and functions called automatically when an object is created.

Adapting the Critiquing Agent Knowledge Base

Each rule in the knowledge base has three parts: *trigger*, *condition*, and *rule information*. The condition-action nature of each rule was captured in the trigger and condition portions, which are themselves expressed in a condition-action form using the Goldworks III rule syntax. The trigger portion of the design code is used to check the solution for the basic applicability of the rule. This involves checking the solution for the correct types of objects and whether or not the particular set of objects has ever been checked before. If the basic applicability conditions are satisfied, the *condition* portion of the rule is invoked. The condition portion usually involves the calculation of a relationship between the two objects, and is generally more expensive to apply than the design code trigger. If the condition portion is satisfied, a note is made of the violation and a critique is generated. The trigger and condition portions of Rule 21 is in Figure 14.

Both the trigger and condition portions are expressed as if-then rules. The antecedent of the trigger portion is a conjunction of conditions. The first two conditions establish the type of objects (here any type of equipment and a hatch) and bind instantiated design objects to the variables (?e1 and ?e2). The third condition (not-equal ?e1 ?e2) ensures that ?e1 and ?e2 are not the same object. The last condition of the trigger checks to see if the rule has been checked previously and found not to be in violation. If it has been checked, then there is no reason to continue with the current rule check. The record of previously checked rules is updated when design objects are moved, resized, or deleted; clearly, if a design object has been modified, then the previous rule checks are no longer valid.

The consequent of the trigger portion asserts a message (a check-condition assertion) for the condition portion of the design code. In particular, it establishes an identification tag for the rule check and the variable bindings for the check. In the case of a user select object request (the error prevention critic), forward chaining of the rules in the knowledge base stops at this point. However, for the error detection and design review critics, and the simple suggestion critic, the condition portion of the rule is then applied. The condition portion of the rule is not applied for the error prevention critic because the information about the shadow object (e.g., the physical

Design Code

Rule 21: Equipment on the roof should be accessible via walkways from a hatch.

Trigger Portion

```
(define-rule rule21-trigger (:priority 100)
   (instance ?e1 is equipment)
   (instance ?e2 is hatches)
   (not-equal ?e1 ?e2)
   (equal (checked-before-dual 'rule21 (list "?e1" ?e1) (list "?e2" ?e2)) '( ))
  THEN
   (check-condition ?new-violation-name ?current-query rule21 (("?e1" ?e1) ("?e2" ?e2))))
```

Condition Portion

```
(define-rule rule21-condition (:priority 0)
   (check-condition ?name ?current-query rule21 ((?t1 ?e1) (?t2 ?e2)))
   (equal (connected? ?e1 ?e2) '( ))
  THEN
  (violation ?name ?current-query rule21 ((?t1 ?e1) (?t2 ?e2))))
```

Figure 14. The trigger and condition portions of a design code.

location, the unique slot values) are not known at that time. This information is known when the other critics and suggestion agents are applied.

The antecedent of the condition portion performs the actual violation check between the objects. In the example, this check is performed in the line (equal (connected? ?e1 ?e2) '()). The connected? relation is implemented as a LISP function that checks to see if the two design objects are accessible via a sequence of walkways. If the relation fails, the equipment object is not accessible via the hatch and a violation message is created, to be processed in the Generate Critiques phase (Stage 5) of the iterative critiquing cycle.

The reason for splitting the trigger and condition portions is discussed in detail in Chapter 4. The *rule frame* portion corresponding to Rule 21 is shown in Figure 15. The rule frame portion contains information about the rule: the variable-object type association list, the rule level, the rule type, and critique generation information.

The variable-object type association list relates the variables in the body of the rule to legally bindable object types in the Design Object Hierarchy. For Rule 21, the variable ?eq1 should be bound to an instance of *Equipment*, and the variable ?eq2 should be bound to an instance of *Hatches*.

The rule level slot defines the level of the rule: physical-level, specification-level, or preference-level.

Each rule may either be an *object-relation* rule or an *object-existence* rule (rule type slot). *Object-relation* rules detect problems between existing objects on the design and are rules used by the critiquing agents; *object-existence* rules make suggestions for adding (or removing) objects to and from the design and hence are used by the simple design suggestion agent.

As was discussed in the second section of this chapter, the critique generation information from the *text*, *bindable-list*, *explanation*, and *violation-action* slots is used to create the graphical and textual critiques described in Chapter 4. The graphical component of the critique is generated from the contents of the violation-action slot and the textual component of the critique is generated from the contents of the explanation slot.

The knowledge base may be spread across several files. For the version of SEDAR for the flat and low-slope roof domain, the files containing the trigger and condition portions of the rules may be found in the sedar\kb subdirectories. Appendix A lists the specific files. When creating a new knowledge base, the knowledge base files for

Instance: RULE21
Parent: DESIGN-CODES
Slots:

Name	RULE21
Level	SPECIFICATION
Rule-Type	OBJECT-EXISTENCE
Permanent	T
Text	"All equipment should be accessible via walkways from the hatch."
Trigger	RULE21-TRIGGER
Condition	RULE21-CONDITION
Object-Driven	RULE21-INTERACT
Bindable-List	((?E1 EQUIPMENT) (?E2 EQUIPMENT))
Explanation	("There should be a walkway from " "?e1" " to " "?e2" ".")
Violation-Action	(MULTIPLE-DRAW (DRAW-BOUNDARY-AREA "?e1" UNKNOWN INTERIOR 0) (DRAW-BOUNDARY-AREA "?e2" RECTANGULAR-COMPOSITION INTERIOR 0))

Figure 15. The Rule Frame.

the flat and low-slope roof domain may be removed by altering the set of files loaded in *a.lsp*. The rule frame portions of the rules are defined with the trigger and condition portions of the rules. The semantic link assertions made in *assert.lsp* should also be updated to reflect the new set of rules in the knowledge base. Finally, the file *kb.lsp* contains a registry of all of the trigger and condition portions of rules in the knowledge base and should be updated to reflect the content of the new knowledge base.

Conclusion

Adapting SEDAR to work with new domains requires the modification of two components of the existing architecture – the domain-specific portions of the Blackboard (the DTM, the Design Object Hierarchy, and the Design Representation) and the domain-specific portions of the Critiquing Agents (the knowledge base). Altering the DTM requires a cognitive task analysis of human experts in the new problem domain. The Design Object Hierarchy defines the fundamental building blocks of solutions for the problem domain. The Design Representation, consisting of object instances and semantic links amongst the object instances, is the system's representation of the human user's partial solution. The semantic links may include links created by the 2-D geometric reasoning routines (discussed in greater detail in Chapter 5) and domain-specific semantic links. The knowledge base consists of domain rules for critiquing the human's solution and for making suggestions. The knowledge base is discussed in greater detail in Chapter 4, which discusses how to use the existing flat and low-slope roof design knowledge base for other applications.

4 The Flat and Low-Slope Roof Knowledge Base

SEDAR Knowledge Base

To date, the flat and low-slope roof design knowledge base is a partial implementation of 120 of the constructibility codes specified in East et al. (1995). While most of the major component types have been addressed in the knowledge base, not all of the codes specified were amenable for use in SEDAR. The codes used in the existing knowledge base pertained to the layout of roof components in the roof field. Some rules pertained to the construction process rather than the design of roofs. Other rules dealt with construction details, a level of specificity not supported by the current version of SEDAR. While the implementation of the codes in East et al. (1995) is incomplete, the existing implementation is believed to be an acceptable starting point for a software system.

Knowledge Base Reuse

Because the constructibility codes are defined as Goldworks III rules, researchers who wish to develop systems for flat and low-slope roofs in Goldworks III may be able to reuse SEDAR's knowledge base. To reuse SEDAR's knowledge base, four components of the current SEDAR system should be retained:

- the files containing the rules in the knowledge base
- the set of roof components defined in the Design Object Hierarchy
- the geometric reasoning libraries (found in *sedar-ge.zip*)
- the semantic links between the roof components.

The necessary components (excluding the geometric reasoning libraries) have been zipped using Pkzip v. 2.04 into the file *sedar-kb.zip*.

The files containing the rules in the knowledge base are in files under the sedar\kb subdirectory. These files are:

- areadiv.lsp

- drains.lsp
- equip.lsp
- expansio.lsp
- roof.lsp
- scuppers.lsp
- vents.lsp

The files contain the trigger and condition portions of the rules shown below:

```
1    (define-rule rule21-trigger (:priority 100)
2      (instance ?e1 is equipment)
3      (instance ?e2 is hatches)
4      (not-equal ?e1 ?e2)
5      (unknown (instance ?e1 is hatches))
6      (unknown (instance ?e1 is walkways))
7      (unknown (instance ?e2 is walkways))
8      (equal (checked-before-dual 'rule21 (list "?e1" ?e1) (list "?e2" ?e2)) '())
9      (bind ?new-violation-name (violation-name))
10     (bind ?current-query *CURRENT-QUERY*)
11   THEN
12     (check-condition ?new-violation-name ?current-query rule21 (("?e1" ?e1)
          ("?e2" ?e2))))
13 (define-rule rule21-condition (:priority 0)
14   (check-condition ?name ?current-query rule21 ((?t1 ?e1) (?t2 ?e2)))
15   (equal (connected? ?e1 ?e2) '())
16 THEN
17   (retract (check-condition ?name ?current-query rule21 ((?t1 ?e1) (?t2 ?e2))))
18   (violation ?name ?current-query rule21 ((?t1 ?e1) (?t2 ?e2))))
```

The antecedent of the trigger portion of the rule contains type checking information (Lines 2 to 7), a check for a previously cached attempt to apply the rule (Line 8), and additional bindings for the unique identification (id) of the rule application attempt (Line 9) and the current query number (Line 10). The consequent of the trigger portion is a single check-condition assertion into the working memory of SEDAR (Line 12), which contains the unique id, the query number, the rule name, and the variable/object binding list. The condition portions of the rules are designed to fire only after all the trigger portions of the rules have been fired. The trigger portions of the rules are assigned a priority of 100 (Line 1), while the condition portions of the rules are assigned a priority of 0 (Line 13). This prioritization allows the system developer to “insert” rules that fire between the application of the trigger and condition portions of the rules. For example, the developer may wish to eliminate

duals of rule applications (described in Chapter 3), which may be accomplished by writing rules at intermediate levels of priority (i.e., less than 100 and greater than 0) that remove dual check-condition assertions. The first line of the antecedent (Line 14) checks for the check-condition assertion made by the trigger portion of the rule and binds the necessary variables. Line 15 contains the possibly expensive check of the relationship between the objects specified in the rule—in this case, ?e1 and ?e2 are checked to see if they are *connected?*. The *connected?* function is a domain-specific function that tries to find a path (defined by walkways) between the roof-mounted equipment bound to ?e1 and the hatch bound to ?e2. If the two components are not connected (i.e., the call to *connected?* returns nil [false]), the rule consequent is applied. In the rule consequent, the original check-condition assertion is replaced with a violation assertion containing the same information. Thus, a record is kept of rule violations (violation assertions) as well as previous rule checks of object relationships that are satisfied by the existing design (the surviving check-condition assertions).

Each of the design codes is also associated with a rule frame component. The rule frame, described in the third section of Chapter 3, contains information pertaining to the applicability of the rule and constraint templates. These templates are non-essential components with respect to reuse of the roof knowledge base, but are included for the additional reference.

To use the set of rules in Goldworks III, the reader is referred to the Goldworks III reference manual, which describes how to add these rules to a rule set and how to apply these rules by activating the rule set, calling the *forward-chain* function, and then deactivating the rule set.

5 Geometric Reasoning Libraries

Description

This component contains LISP functions for computing various quantities and properties related to the geometric positions of shapes in a 2-D Cartesian coordinate system. Two files contain geometric reasoning routines:

geometry.lsp
decomp.lsp

The geometric reasoning functions in each of these files use filtering processes to quickly eliminate obviously false solutions. Additionally, these function cache previously computed geometric relationships on the blackboard to speed up computation. These two files are included in the zipped file *sedar-ge.zip*. Finally, this library assumes that objects are represented in terms of two types of shapes: circles and rectangular-compositions, which are described below.

Data Structures

The functions in this component take *objects* as their arguments. These objects should be Goldworks instances. They must have a *shape-type* slot, and the slot-value for this must be *rectangular-composition* or *circle*. Each object must have a coordinate-info slot.

If the object is a circle, the coordinate-info slot contains the center point of the object, which is a two-element list, representing x-y coordinates. The object must also have a "radius" slot containing the radius of the circle.

If the object is a rectangular-composition, the coordinate-info slot contains a list of the vertices of the rectangular-composition. In addition, the object must have an *extent* slot containing a list of two points that represent the bounding box for the rectangular-composition. There must also be slots called *vertical-borders* and *horizontal-borders*, containing lists of borders. A border is a two-element list (location extent). The location of a vertical-border is its x-location, and the extent of a

vertical-border is a list of two y-coordinates. The location of a horizontal-border is its y-location, and the extent of a horizontal-border it a list of two x-coordinates.

Example Data Structures

The circle and rectangular-composition frames are:

```
(DEFINE-FRAME CIRCLE
  (:IS OBJECT-GEOMETRY)
  (COORDINATE-INFO :CONSTRAINTS (:LISP-TYPE LIST))
  (RADIUS :CONSTRAINTS NIL :DEFAULT-VALUES (0.25))
  (SHAPE-TYPE :DEFAULT-VALUES (CIRCLE)))

(DEFINE-FRAME RECTANGULAR-COMPOSITION
  (:IS OBJECT-GEOMETRY)
  (COORDINATE-INFO :DEFAULT-VALUES (NIL)
      :CONSTRAINTS (:LISP-TYPE LIST))
  (VERTICAL-BORDERS :DEFAULT-VALUES (NIL)
      :CONSTRAINTS (:LISP-TYPE LIST))
  (HORIZONTAL-BORDERS :DEFAULT-VALUES (NIL)
      :CONSTRAINTS (:LISP-TYPE LIST))
  (SHAPE-TYPE :DEFAULT-VALUES (RECTANGULAR-COMPOSITION))
  (EXTENT :DEFAULT-VALUES (NIL)
      :CONSTRAINTS (:LISP-TYPE LIST)))
```

A portion of an instance of the circle frame is:

```
  (:IS ATTIC-VENTS)
  (COORDINATE-INFO (62.7 36.2))
  (RADIUS 0.25)
  (SHAPE-TYPE CIRCLE)
```

A portion of an instance of the rectangular-composition frame is:

```
  (:IS AC-UNITS-CURBED)
  (COORDINATE-INFO ((86.3 62.7) (89.3 62.7) (89.3 59.7) (86.3 59.7)))
  (VERTICAL-BORDERS ((86.3 (59.7 62.7)) (89.3 (59.7 62.7))))
  (HORIZONTAL-BORDERS ((59.7 (86.3 89.3)) (62.7 (86.3 89.3))))
  (SHAPE-TYPE RECTANGULAR-COMPOSITION)
  (EXTENT ((86.3 59.7) (89.3 62.7)))
```

Major Functions and Their Return Values

In geometry.lsp:

(compute-distance object1 object2) - Given two objects, find the minimum distance between the objects.

(complete-overlap object1 object2) - Returns 't if object2 is completely contained within object1. Returns nil if not.

(no-overlap object1 object2) - Returns 't if object1 and object2 have no overlap except possibly on a point or a line. Returns nil otherwise.

(adjacent object1 object2) - Returns 't if object1 touches object2. Returns nil otherwise.

(intersection object1 object2) - Returns 't if object1 intersects object2, nil otherwise. This function is the opposite of no-overlap.

(aligned object1 object2 tolerance) - Given two adjacent objects, returns 't if one of their edges is aligned within the given tolerance. Returns nil otherwise.

(next-to-outside object1 object2) - Returns 't if object1 is next to object2 on the outside. Returns nil if not.

(next-to-inside object1 object2) - Returns 't if object2 is completely contained within object1 and is next to object1. Returns nil otherwise.

(area-of object) - Given an object, lookup or compute its area and return it.

(compute-distance object1 object2) - Computes and returns the distance between two objects.

(north-of rect1 rect2)

(south-of rect1 rect2)

(east-of rect1 rect2)

(west-of rect1 rect2) - Given two rectangular areas (simple rectangular areas, not complex rectangular composition), return 't if the desired relative positions are true. Returns nil otherwise.

(exceeds-max-distance-p obj obj2 maxd) - This function is intended to quickly check if the distance between two objects exceeds maxd. Note that if this function returns T, the two objects are definitely more than maxd apart. However, if this function returns nil, the objects might still be more than maxd apart. The purpose of this function is to quickly filter out pairs of objects that are far apart.

In decomp.lsp:

(maximum-decomposition rect-obj) - Takes as argument the name of a rectangular-composition. Returns a list of the maximal set of simple rectangular regions making up the rectangular-composition.

(horizontal-decomposition rect-obj) - Takes as argument the name of a rectangular composition. Returns a list of the set of horizontal slices of the rectangular composition. Each slice is a simple rectangular region.

(vertical-decomposition rect-obj) - Takes as argument the name of a rectangular composition. Returns a list of the set of vertical slices of the rectangular composition. Each slice is a simple rectangular region.

(subtract-area start-list subtract-list) - Takes as arguments two lists of rectangular extents. Geometrically "subtracts" the extents in subtract-list from start-list and returns what is left. More precisely, the areas of overlap between start-list and subtract-list are removed from start-list and the remainder is returned as a list of rectangular extents (or possibly an empty list if nothing is left).

Besides these major functions, numerous supporting functions have also been written for the geometric reasoning library, and are contained in the files *geometry.lsp* and *decomp.lsp*.

6 AutoCAD Information Display Functions

Besides the reuse of the user interface in the context of the expert critiquing shell, two aspects of the interface may be reused by interface developers working within AutoCAD. The first reuse component is that of the text display boxes used to display the textual portions of critiques in the AutoCAD drawing screen (Figure 16). The second reuse component is the design objects dialog box used to select an object from a palette (Figure 17). Each of these components is described below and included in the file *sedar-ac.zip*.

Text Display Boxes

File: *ac-expl.lsp* — This component contains AutoLISP functions for displaying textual explanations in a solid rectangle overlaying an AutoCAD design. The explanation box may be temporarily displayed and then erased without affecting the rest

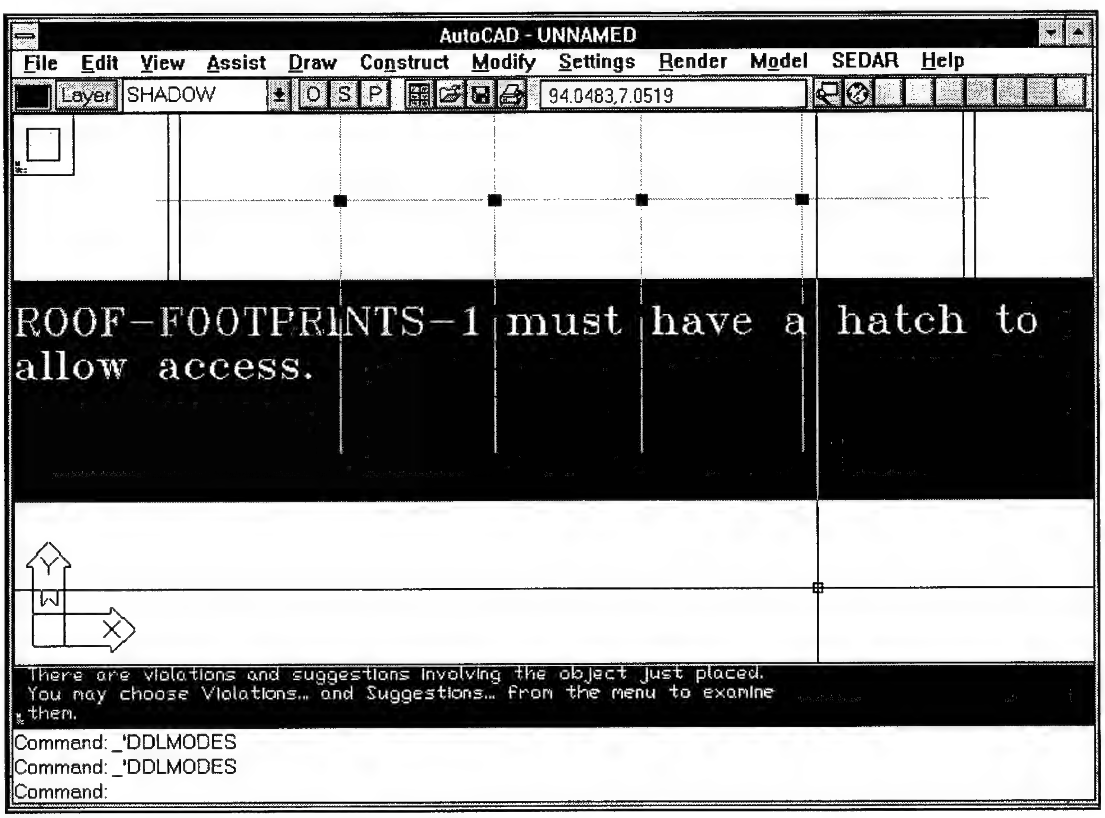

Figure 16. Example of a text display box.

of the drawing. The explanation box is drawn on a layer called the SHADOW layer. This layer needs to be created elsewhere.

The color of the explanation box will be the default color of the SHADOW layer. The text will be white, except for the object names, whose colors are determined by the function get-color-from-violation-type and the global variable *SECONDARY-COLOR*.

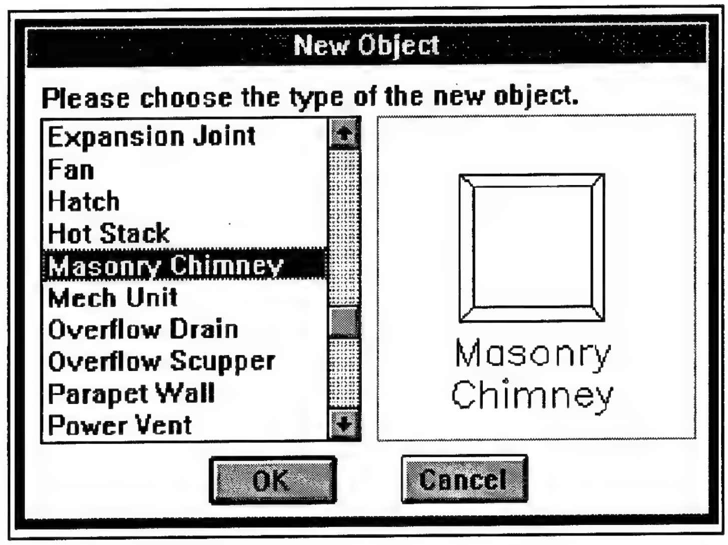

Figure 17. SEDAR architecture.

Major Function

(draw-explanation-box-and-text object-list explanation-list violation-level)

Parameters: object-list: List of names of objects involved in the explanation

explanation-list: The explanation in the form of a list of strings. Object names are separate strings, with a leading ? as a sentinel.
Here is a sample explanation-list:
("There should be a walkway from "
"?AC-UNITS-CURBED-1" " to " "?HATCHES-1"
".")

violation-level: Either physical, specification, or preference

This function may be reused in multiple ways. If used in an expert critiquing system that provides explanations of violations, then it can be used as it was originally intended. The object-list will contain the list of objects in the design that are referred to in the explanation. When the explanation box is displayed, the object names within the explanation will be colored differently from the rest of the text.

Alternatively, this function can be used simply to write out any string in a box overlaying an AutoCAD design. In this case, object-list and violation-level would be set to nil. Explanation-list would be a list of one element—the string to be displayed.

Note that this function does not check if the text will fit within the explanation box. Four lines of text will fit with the given settings.

Supporting Functions

(lower-left-of-exp-box object-list)
(draw-explanation-box the-point)
(get-first-word string)
(trim-leading-whitespace string)
(get-leading-whitespace string)
(all-spaces string)
(fits str-test left-x right-x ht)
(my-textbox string height)
(show-text string start-location left-margin right-margin line-ht char-ht
    tlw end-pt)
(object-name-p string)
(process-explanation-list explanation-list violation-type color-num start-
    location left-margin right-margin line-ht char-ht tlw)
(draw-explanation-text lower-left explanation-list level)

The Design Objects Dialog Box

Files: *ac-objs.lsp, globals.lsp, objects.dcl, *.sld* — This component contains routines for displaying an AutoCAD dialog box showing names of design objects and their corresponding images. A list of names scrolls on the left, and one image is shown on the right. Whenever the user clicks on an object name, the image of that object is displayed. The information about objects and their images needs to be stored in a global variable called *OBJECTS*. The images themselves need to be stored in individual AutoCAD slide (.sld) files. The main function, *get-new-object-type*, has been separated from the rest of *ac-shell.lsp* and put into a file called *ac-objs.lsp*.

More generally, this dialog box could be used in any situation in an AutoCAD application in which a user must select one item out of a list, and each item has a corresponding image. A sample of the *OBJECTS* global variable is:

```
(setq *OBJECTS*
  Type              Dialog text name      Slide      Block      Shape                      Size
  ------            -----------------     -------    --------   ---------                  ------
'(
 (ac-units-curbed  "AC Unit on Curb"     "ac-curb"  "ac-curb"  rectangular-composition   3.0)
 (ac-units-sleeps  "AC Unit on Sleep"    "ac-sleep" "ac-sleep" rectangular-composition   3.0)
 (area-dividers    "Area Divider"        "areadiv"  nil        nil                       nil)
 (attic-vents      "Attic Vent"          "vent"     "vent"     circle                    0.25)
))
```

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Appendix A: Files and Locations

Goldworks III Files

In the *gcl44\sedar* subdirectory:

cma-fn.lsp
cma-main.lsp
cma-rule.lsp
decomp.lsp
demons.lsp
geometry.lsp
prevdet.lsp
review.lsp
snap.lsp
update.lsp
violate.lsp

In *gcl44\sedar\kb* subdirectory:

areadiv.lsp
assert.lsp
drains.lsp
equip.lsp
expansio.lsp
frames.lsp
kb.lsp
obj-fn.lsp
obj-rule.lsp
roof.lsp
scuppers.lsp
vents.lsp

AutoCAD Files

In the *sedar* directory:

Autolisp Files (*.lsp)

ac-expl.lsp
ac-init.lsp

ac-shell.lsp
attribs.lsp
globals.lsp
handlers.lsp
init.lsp
setup.lsp
slots.lsp

Drawing Files (*.dwg)

ac-curb.dwg
ac-sleep.dwg
ac-unit.dwg
areadiv.dwg
chim.dwg
chimney.dwg
column.dwg
drain.dwg
exh-fan.dwg
expjoint.dwg
fan.dwg
hatch.dwg
hotstack.dwg
hs.dwg
hvac.dwg
od.dwg
odrain.dwg
parwall.dwg
pv.dwg
pvent.dwg
rd.dwg
rdrain.dwg
rh.dwg
roofhatc.dwg
rv.dwg
rvpipe.dwg
scupper.dwg
sump.dwg
vent.dwg

DCL Files (*.dcl)

attribs.dcl
goals2.dcl
objects.dcl

slots.dcl
suggest.dcl
violatns.dcl

Slide Files (*.sld)
1slope.sld
2slope.sld
4slope.sld
ac-curb.sld
ac-sleep.sld
ac-unit.sld
areadiv.sld
chimney.sld
drain.sld
exh-fan.sld
expjoint.sld
fan.sld
hatch.sld
hotstack.sld
hvac.sld
odrain.sld
parwall.sld
pvent.sld
rdrain.sld
rooffoot.sld
roofhatc.sld
rvpipe.sld
scupper.sld
vent.sld
walkway.sld

In the *acadwin* directory:
acad.mnl
acad.mnu
cadreglb.lsp

Appendix B: Function Listings by File

Expert Critiquing Shell Files

File: cma-main.lsp

Function
Arguments

user::ac-message
query-id msg-string &rest msg-info
convert-from-string
arg
deep-convert-from-string
arg
do-get-object-slots
lst
do-get-object-slot-values
lst
do-get-object-slot-values*
object-id slot-list
do-get-object-slot-defaults
lst
do-get-object-slot-defaults*
object-id slot-list
do-get-object-children
request lst
inorder-traversal
frame-name
do-get-object-parents
request lst
do-modify-slot-values
lst
do-modify-slot-values*
object-id slot-value-list
do-get-dtm-all

do-get-dtm-activations
    activation
get-all-dtm-activations

do-get-dtm-task-status
    lst
do-get-dtm-tasks
    relation-type task
do-set-dtm-task-activation
    lst
do-get-dtm-task-rules
    lst
do-rule-query
    query-type lst
get-rule-info
    rule-name
do-rule-activation
    activation lst
do-set-review-type
    lst
do-set-critique-type
    critique-type lst
do-reject-critique
    lst
update-kb
    query-id msg-string &optional msg-info
update-tasks
    query-id object-type
recently-activated
    query-num task
recently-activated*
    query-num task depth
task-update-situation-p
    query-num
do-delete-object
    msg-info
do-delete-object*
    obj
delete-assertions
    obj-name
do-review-tasks
    msg-string &optional msg-info

do-select-object
    msg-info
remove-nils
    lst
do-place-object
    msg-info
do-move-object
    msg-info
do-resize-object
    msg-info
get-object-descriptions

File: cma-fn.lsp

Function
    Arguments

null?
    x
sqr
    x
minimum
    lst
maximum
    lst
filter
    f lst
filter-mapcar
    filter-fn map-fn lst
clear-all

n-last
    n llist
n-last*
    threshold current llist
violation-name

combine
    f zero list
count
    elt list
count-objects
    the-frame big-instance

set-start-time

print-elapsed-time

detail-list-test

e1 e2

assert-subtask-list

subtasks parent

check-and-activate-tasklist

tasklist

make-object-instance

msg-info

apply-lisp-functions

arg func-list

legal-object?

object-type

frame-ancestor

ancestor descendant

frame-ordered

task1 task2

frame-ordered*

task1 task2 task1-parents task2-parents

frame-ordered**

task task-list

all-frame-instances

frame

File: decomp.lsp

Function

Arguments

maximum-decomposition

rect-obj

horizontal-decomposition

rect-obj

combine-horizontal-areas

area-list

combine-horizontal-areas*

area-list combined-area-list

combine-area-horizontally

extent extent-list

vertical-decomposition
    rect-obj
combine-vertical-areas
    area-list
combine-vertical-areas*
    area-list combined-area-list
combine-area-vertically
    extent extent-list
filter-out-rectangles
    rect-list rect-obj
make-h-slices
    extent h-borders
make-h-slices*
    h-borders extent current-y
make-v-slices
    h-slice-list extent v-borders
make-v-slices*
    h-slice-list current-x v-borders
make-v-slices**
    h-slice current-x v-borders
subtract-area
    start-list subtract-list
subtract-area*
    left subtract-list
remove-rectangle
    left sub-area
one-corner-extent-overlap
    extent1 extent2
two-corner-extent-overlap
    extent1 extent2
one-side-extent-overlap
    extent1 extent2
two-side-extent-overlap
    extent1 extent2
num-intersecting-corners
    extent1 extent2
num-intersecting-corners*
    point-list extent
form-complete-overlap-remainder
    extent1 extent2
form-one-corner-remainder
    extent1 extent2

form-two-corner-remainder
extent1 extent2
form-one-side-remainder
extent1 extent2
form-two-side-remainder
extent1 extent2

File: geometry.lsp

Function
Arguments

border-order
e1 e2
make-vertical-borders
coord-list
make-vertical-borders*
coord-list
make-horizontal-borders
coord-list
make-horizontal-borders*
coord-list
legal-composition
coord-list
legal-composition*
current-coord rest-list
make-extent
coord-list
make-extent*
coord-list min-x min-y max-x max-y
make-coord-info
extent
point-distance
point1 point2
point-in-rect
point rect
point-in-rect1
point v-borders
on-horizontal-border
x-val y-val horizontal-borders
on-vertical-border
x-val y-val vertical-borders

num-right-crossings
x-val y-val vertical-borders
num-border-crossings
point1 point2 border-list direction
complete-extent-overlap
extent1 extent2
no-extent-overlap
extent1 extent2
point-in-extent
point extent
point-strictly-in-extent
point extent
complete-overlap
object1 object2
complete-overlap-cc
circle1 circle2
complete-overlap-rr
rect1 rect2
complete-overlap-rr*
rect1 coordlist1 coordlist2 v-borders h-borders
check-all-borders
coordlist1 v-borders h-borders
complete-overlap-rc
rect1 circle1
complete-overlap-rc*
coordlist center radius rect
segment-within-distance
endpt1 endpt2 point distance
segment-within-distance*
pt1 pt2 point distance direction
no-overlap
object1 object2
no-overlap-cc
circle1 circle2
no-overlap-rr
rect1 rect2
no-overlap-rr*
rect1 coordlist1 coordlist2 v-borders h-borders
no-overlap-rc
rect1 circle1
no-overlap-rc*
coordlist center radius rect

next-to-outside
object1 object2
next-to-inside
object1 object2
simple-span-extent
extent1 extent2 tolerance
simple-span-rr
rect-obj1 rect-obj2 tolerance
simple-span-extent
extent1 extent2 tolerance
simple-span-extent-rr
extent1 extent2 tolerance
spans-roof
obj roof-obj
spans-roof*
obj extent-list
next-to-cc
circle1 circle2
next-to-rc
rect circle
adjacent
object1 object2
adjacent-cc
circle-obj1 circle-obj2
adjacent-rc
rect-obj circ-obj
rect-segments-touch-circle
h-borders v-borders center radius
get-first-coord
border
get-second-coord
border
rect-points-touch-circle
coord-list center radius
adjacent-rr
rect-obj1 rect-obj2
check-colinearity-overlap-segments
borders1 borders2
check-colinearity-overlap-segments*
border border-list
intersection
object1 object2

adjacent-on-edge
object1 object2 object2-side
intersect-on-edge
object1 object2 object2-side
aligned
object1 object2 tolerance
area-of
object
area-of-c
circle
area-of-rc
rect
area-of-rc*
h-borders v-borders left-x right-x area
area-of-rc**
y-coord delta-y right-x v-border-list
pop-border-list
h border-list
pop-border-list*
h last-elt rest-list
filter-heights
h1 h2 v-border-list
traversable
obj1 obj2 path-obj
connected?
obj1 obj2
check-walkway-objects
obj1 obj2 walkway
object-connected
object-list target-obj
connected?*
obj1 obj2 current-walkway
get-relative-distance
object border-list border-type
get-relative-distance-circle
center radius border-list border-type
get-relative-distance-rect
coordinate-info extent border-list border-type
compute-distance
obj1 obj2
compute-distance-cc
circle-obj1 circle-obj2

compute-distance-rc
rect-obj circle-obj
distance-to-corners
corner-list center radius
distance-to-vert-borders
border-list center radius
distance-to-horiz-borders
border-list center radius
compute-distance-rr
rect-obj1 rect-obj2
rect-comps-dist
rect-comp1 rect-comp2
rect-comps-dist-aux
rect-comp1 rect-comp2
rect-comp-point-dist
rect-comp point
draw-point
point
edge-point-dist
point edge
vert-edge-point-dist
point edge
horiz-edge-point-dist
point edge
pointx
point
pointy
point
edgex1
edge
edgey1
edge
edgex2
edge
edgey2
edge
distance
point1 point2
opposite-orientation
orientation
distance-to-line
point line

get-edge
simple-rectangle edge
horizontal?
line
vertical?
line
north-of
rect1 rect2
north-of-extent
rect1-extent rect2-extent
south-of
rect1 rect2
south-of-extent
rect1-extent rect2-extent
west-of
rect1 rect2
west-of-extent
rect1-extent rect2-extent
east-of
rect1 rect2
east-of-extent
rect1-extent rect2-extent
determine-alignment
rect1 rect2
determine-alignment-extent
rect1-extent rect2-extent
line-distance
line1 line2
exceeds-max-distance-p
obj1 obj2 maxd

File: prevdet.lsp

Function
Arguments

build-rule-object-type-list
agent rule-name
first-highest-priority-task
task-list
max-priority
a-task a-priority

get-active-rules
    agent
get-active-rules-for-object-place
    agent
build-rule-task-list
    agent rule
check-intersection
    list1 list2
make-object-place-ruleset
    active-rule-list
make-object-select-ruleset
    active-rule-list
make-od-rule
    new-rule-name old-rule-name trigger-name object-list bindable-list
make-new-consequent
    old-consequent bindings rule-name
make-new-antecedent
    old-antecedent bindings
instantiate
    s-exp binding-list
instantiate-binding
    s-exp binding quote-p
form-binding
    object-list bindable-list
form-binding*
    object-list prev-bindable-list rest-bindable-list

File: review.lsp

Function
    Arguments
make-all-review-rules
    agent
make-all-focus-review-rules
    agent
make-review-rules-for-task-subtree
    agent task
make-review-rules
    agent task-list
activate-rules-by-tasks
    agent task-list

File: snap.lsp

Function
Arguments

snap-to-fit-circle-point
circ-obj point
snap-one-slope-das
one-slope-das
snap-four-slope-das
four-slope-das
snap-drainage-area
one-slope-das tolerance
equal-extents
extent1 extent2
align-adjust-width-rr
snapper snappee
find-nearest-adjacent-edge
obj1 obj2

File: update.lsp

Function
Arguments

update-assert
object-type current-agent
filter-deactivated-tasks
task-list
get-tasks
rule-list current-agent
get-interfering-tasks
task-list current-agent
get-last-tasks

filter-recently-activated
task-assertion-list

File: violate.lsp

Function
Arguments

order-by-tasks

rule-task-pair-compare

rule-task-pair1 rule-task-pair2

task-compare

task1 task2

sort-by-priority-reverse

rule-list

order-by-tasks-select

make-violation-action

violation-name rule-name task-name level rule-type var-bindings

violation-action explanation

make-select-violation-action

constraint-area-name obj-type rule-num task level obj-id bindable-list

binding-list explanation violation-action

get-binding

var binding-list

make-explanation

explanation var-bindings

cat-explanation-terms

inst-expl

make-explanation-list

explanation var-bindings

cat-explanation-terms-2

inst-expl

make-object-list

var-bindings

make-object-list

explanation var-bindings

object-variable-p

str

get-object-string-assoc

obj-type binding-list

get-other-object-string-assoc

obj-id binding-list bindable-list

get-var-name

obj-id binding-list

get-other-object-string-assoc*

var-name bindable-list

get-partial-action

var violation-action

get-partial-action*

var action-list

string-member
sym lst
atomic-listp
lst
var-obj-instantiate
var obj-id lst

Flat and Low-Slope Roof Knowledge Base Files

File: kb.lsp

Function
Arguments

binding-list-match
binding-list1 binding-list2
checked-before-dual
rulenum &rest binding-list
checked-before
rulenum &rest binding-list

File: obj-fn.lsp

Function
Arguments

make-assoc-id

make-penetration-id

make-slice-id
direction
make-wall-segment-id

make-roof-drains-id

make-column-id

make-roof-walls
roof-footprints-id
make-roof-walls*
roof-footprints-id coord-info width point1 point2 list-length

get-bounding-points
pt1 pt2 pt3 pt4
classify-corner
pt1 pt2 pt3
make-roof-edges
roof-footprints-id
make-expansion-joint-points
roof-footprints-id
make-joint-points*
roof-id area-list direction
make-joint-points-h**
roof-id area area-list
make-joint-points-v**
roof-id area area-list
complete-expansion-joint-slots
joint-obj
clip-or-extend-to-roof
obj roof-obj
clip-or-extend-to-roof*
obj extent-list
clip-or-extend-rc-objects
obj extent
make-footprint-slices
roof-obj
make-footprint-slices*
area-list roof-obj slice-type
test-cricket
low-point edge-point1 edge-point2 obj
make-line
point1 point2
check-corners
line coord-list
which-cricket
four-slope-da obj
make-wall-segments
wall
make-wall-segments*
endpoint1 endpoint2 endpoint-list half-width wall-id segment-count
assess-spacing
slice distance-interval
assess-spacing*
slice distance-interval

check-distance-intervals
offset-list interval list-length
create-low-point-drain
four-slope-da
make-columns
column-list
do-vertical-column-lines
column-list endpt1 endpt2 height
do-horizontal-column-lines
column-list endpt1 endpt2 height

User Interface (AutoLisp) Files

File: ac-expl.lsp

Function
Arguments

draw-explanation-box-and-text
object-list explanation-list violation-level / lower-left
lower-left-of-exp-box
object-list
in-middle-third
object-name / shape center radius rc y-maxmin top bottom
in-bottom-third
object-name / shape center radius rc y-min
in-top-third
object-name / shape center radius rc y-max
in-all-3-regions
object-name
draw-explanation-box
the-point
str-to-sym
string
get-first-word
string / whtspc
get-first-word-aux
string
trim-leading-whitespace
string
get-leading-whitespace
string

all-spaces
    string

fits
    str-test left-x right-x ht

my-textbox
    string height

show-text
    string start-location left-margin right-margin line-ht char-ht tlw end-pt /

str-fits
    str-test remainder done next-word new-end-pt

object-name-p
    string

process-explanation-list
    explanation-list violation-type color-num start-location left-margin right-margin line-ht char-ht tlw / string new-color-num

draw-explanation-text
    lower-left explanation-list level

erase-shadow-layer

draw-message-text
    string

draw-message-text-at-line
    string line-num

draw-message-text-at-location
    string start-location

erase-message-window
    / selset

make-message-window-blue

File: ac-init.lsp

Function
    Arguments

init-log-file

File: ac-shell.lsp

Function
    Arguments

filter
    f lst

position

item the-list

position-aux

item the-list n

violation-types

violations-list / tmp

violation-message

the-string / viol-types

save-roof-layout

save-globals

pathname

open-roof-layout

toggle-influencer-mode

toggle-debiaser-mode

delete-object-callback

resize-object-callback

c:done

change-object-slot-values

move-object-callback

get-object-constraint-layers

object-name

get-object-constraint-layers*

actions object-name

offset-layers-bounds

layers delta-x delta-y

new-object-callback

get-new-object

/ viol-types

create-new-objects

objects

create-new-object

object

add-if-not-null
    x
get-new-object-type

object-list-click-callback

hierarchic-stringify
    l
hierarchic-stringify*
    l prefix-string
hierarchic-stringify-children
    children prefix-string
active-state-string
    task
get-active-state
    tasks task
on-state-string
    task
add-task
    task
tasks-callback
    / *tasks-orig*
activate-task

deactivate-task

turn-task-on
    / *old-task new-task*
turn-task-off
    / *old-task new-task*
perform-task-activations

perform-task-activations-aux
    changes tasks-list-click-callback
mk_list
    readlist displist / *count item retlist*
violations-callback
    / *true-violations-list*
suggestions-callback
    / *suggestions-list*
get-some-violations
    violations-list violation-type rule-type

get-some-violations

violations-list violation-type

physical-violations-list-click-callback

specification-violations-list-click-callback

preference-violations-list-click-callback

view-violation-callback

shift-coordinates

deltax deltay coords

forget-object-constraints

object

forget-object-constraints-aux

action-layers object

forget-object-constraint

action-layer object

action-depends-on-object

action object

subactions-depend-on-object

subactions object

get-object-shape

obj-type

get-dwg-object-center

object-name

get-dwg-object-radius

object-name

get-dwg-object-entity

object-name

get-dwg-object-type

object-name

get-dwg-object-vertices

object-name

delete-from-dwg-object

object-name

delete-from-dwg-object*

obj-name obj-list

get-dwg-object-from-entity

ent

get-dwg-object-from-entity*

ent obj-list

call-gcl

msg msg-info

stringify

x

perform-review-actions

msg-string msg-info / viol-types

perform-critique-actions

critique / lower-left

get-violation-level

critique

get-rule-type

critique

get-critique-action

critique

get-critique-explanation

critique

get-object-list

critique

get-explanation-list

critique

show-constraints

constraints object-list

draw-constraint-actions

object-list

draw-constraint-action

constraint-action object-list / action layer-name

get-color-from-violation-type

violation-type

create-and-color-constraint-layers

constraints object-list

create-and-color-constraint-layer

constraint object-list

thaw-critique-layers

critique-list

freeze-critique-layers

critique-list

build-critique-layer-list

critique-list

thaw-layers

layer-list

thaw-layers*

layer-list

freeze-layers

layer-list

freeze-layers*

layer-list

generate-constraint-block

constraints block-name object center

draw-constraint-layers

constraints

build-constraint-block

layers block-name object center

build-constraint-block-filter

layers

draw-layers-bounding-box

layers

find-layers-bounding-box

layers

draw-critique-explanation

critique-explanation

draw-attention-text

text

draw-thinking-text

draw-critique

critique-action object-list

show-critique

critique-action critique

draw-outline

object-name shape

draw-arrow

source-action dest-action object-list

map-shadow-points

points

map-shadow-point

point

find-nearest-point

point points

find-nearest-point-aux

point points nearest second-nearest

draw-shadow-object

object-type location

draw-exterior-circle-constraint

object-name size

draw-interior-circle-constraint

object-name size

draw-circle-constraint

object-name hatch

draw-rc-constraint

object-name hatch

draw-exterior-rc-constraint

object-name size

draw-interior-rc-constraint

object-name size

draw-boundary-area

object-name shape boundary-type size

clear-violation

clear-violation-aux

constraint-layers

upto

elt lst

first

lst

second

lst

third

lst

fourth

lst

fifth

lst

sixth

lst

seventh

lst

eighth

lst

ninth

lst

get-x-maxmin

coord-list

get-x-maxmin*

coord-list maxval minval

get-y-maxmin

coord-list

get-y-maxmin*
    coord-list max min
gensym
    object-type
draw-rect-comp
    rect-comp
draw-rect-comp-aux
    rect-comp
draw-outside-rect-comp
    rect-comp radius
draw-outside-rect-comp-aux
    rect-comp radius direction
draw-right
    x y next-direction radius
draw-left
    x y next-direction radius
draw-up
    x y next-direction radius
draw-down
    x y next-direction radius
draw-inside-rect-comp
    rect-comp radius
draw-inside-rect-comp-aux
    rect-comp radius direction
draw-inside-right
    x y next-direction radius
draw-inside-left
    x y next-direction radius
draw-inside-up
    x y next-direction radius
draw-inside-down
    x y next-direction radius

File: globals.lsp

Function
    Arguments

id
    x

File: attribs.lsp

Function
Arguments

change-attribs
object-name
stringify-elements
l
stringify-pairs
l
attribs-list-click-callback

File: handlers.lsp

Function
Arguments

get-attic-vents

create-attic-vents
object-info
get-hot-stacks

create-hot-stacks
object-info
get-overflow-drains

create-overflow-drains
object-info
get-roof-drains

create-roof-drains
object-info
get-roof-vent-pipes

create-roof-vent-pipes
object-info
get-fans

create-fans
object-info

get-circular-object

    radius

create-circular-object

    object-info block-filename

get-ac-units-curbed

create-ac-units-curbed

    object-info

get-ac-units-sleeps

create-ac-units-sleeps

    object-info

get-exhaust-fans

create-exhaust-fans

    object-info

get-mech-units

create-mech-units

    object-info

get-power-vents

create-power-vents

    object-info

get-hatches

create-hatches

    object-info

get-masonry-chims

create-masonry-chims

    object-info

create-columns

    object-info

get-rectangular-object

    width height

create-rectangular-object

    object-info block-filename

get-walls

create-wall-segments

    object-info

get-scuppers

create-scuppers
object-info
get-walkways

create-walkways
object-info
get-roof-footprints

create-roof-footprints
object-info
get-exp-joints

create-exp-joints
object-info
get-area-dividers

create-area-dividers
object-info
get-column-lines

create-column-lines
object-info
get-four-slope-das

create-four-slope-das
object-info
get-two-slope-das

create-two-slope-das
object-info
get-one-slope-das

create-one-slope-das
object-info
convert-da-to-rc
da
get-rc

get-ortho-pline
prompt
input-pline
layer-name
get-ww

normalize-rc

points

make-rc-start-right

points

clean-up-rc

points

clean-up-rc*

points cleaned-points

clean-up-segment

point1 point2

offset

points xoffset yoffset

compute-ww-rc

path radius

get-direction

this-point next-point

compute-ww-side-1

path radius

continue-path-1

path last-direction radius

find-next-ww-point-1

this-x this-y this-direction last-direction radius

compute-ww-side-2

path radius

continue-path-2

path last-direction radius

find-next-ww-point-2

this-x this-y this-direction last-direction radius

make-clockwise

path

is-clockwise

path

is-clockwise*

path total

turn-value

last-direction this-direction

convert-pline-to-rc

layer-name

get-pline-vertices

entity

get-da

drawing-fn

find-max-min

pin-mouse-point

draw-4slope

draw-2slope

draw-1slope

wrap-rc-coords
rect-comp

File: setup.lsp

Function
Arguments

S::STARTUP

File: acad.mnl

Function
Arguments

move-object

new-object

resize-object

delete-object

ai_tiledvp_chk

ai_tiledvp
num ori / ai_tiles_g ai_tiles_cmde

ai_tab1

ai_tab2

ai_tab3

ai_tab4

merr

msg

merrmsg

msg

c:rectang

/ cmde pt1 pt2

c:ai_peditm

/ m:p0 m:p1

m:p0

/ m:s1 m:e1 m:e2 m:e3

m:p1

/ m:a

ai_rootmenus

Appendix C: Rules and Rule Set Listings by File

Expert Critiquing Shell Files

File: cma-rule.lsp

Rule Set Definitions
Rule Set Rules

clear-cache-information
remove-cache-info1
remove-cache-info2
remove-cache-info3
remove-relation-info1
remove-relation-info2
remove-relation-info3
remove-relation-info4
remove-relation-info5
remove-relation-info6

mark-active-rules
deactivate-active-rules

Rule Definitions

remove-cache-info1
remove-cache-info2
remove-cache-info3
remove-relation-info1
remove-relation-info2
remove-relation-info3
remove-relation-info4
remove-relation-info5
remove-relation-info6
deactivate-active-rules

File: demons.lsp

Rule Set Definitions

Rule Set Rules

all-demons

clear-all-shadow-objects1
clear-all-shadow-objects2
clear-all-active-rules
clear-all-temporary-rules
clear-all-temporary-rules-prime
clear-all-violations
clear-all-violations-prime
clear-constraint-rule-set
clear-all-interact-rules
clear-all-interact-rules-prime
clear-task-list
mark-task-list
mark-task-list-prime
unmark-task-list
unmark-task-list-prime
clear-all

Rule Definitions

clear-all-shadow-objects1
clear-all-shadow-objects2
clear-all-active-rules
clear-task-list
clear-all
mark-task-list
mark-task-list-prime
unmark-task-list
unmark-task-list-prime
clear-all-temporary-rules
clear-all-temporary-rules
clear-all-violations
clear-all-violations-prime
clear-constraint-rule-set
clear-all-interact-rules
clear-all-interact-rules-prime

File: update.lsp

Rule Set Definitions
Rule Set Rules

update-tasks-frame
update-tasks-frame1
update-tasks-frame2
update-tasks-copy
update-tasks-copy1
update-tasks-copy2

Rule Definitions

update-tasks-frame1
update-tasks-frame2
update-tasks-copy1
update-tasks-copy2

Flat and Low-Slope Roof Knowledge Base Files

File: areadiv.lsp

Rule Definitions

ruleF-1-trigger
ruleF-1-condition
ruleF-2-a-trigger
ruleF-2-a-condition
ruleF-2-b-trigger
ruleF-2-b-condition
ruleF-2-c-trigger
ruleF-2-c-condition
ruleF-3-trigger
ruleF-3-condition
ruleF-1-1-2-trigger
ruleF-1-1-2-condition
ruleF-1-3-1-a-1-trigger
ruleF-1-3-1-a-1-condition
ruleF-1-3-1-a-2-trigger
ruleF-1-3-1-a-2-condition
ruleF-1-3-1-b-trigger

ruleF-1-3-1-b-condition
ruleF-1-3-1-c-trigger
ruleF-1-3-1-c-condition

File: drains.lsp

Rule Definitions

rule1-trigger
rule1-condition
rule2-trigger
rule2-condition
rule3-trigger
rule3-condition
rule4-trigger
rule4-condition
rule17-trigger
rule17-condition
rule22-trigger
rule22-condition
ruleO-4-trigger
ruleO-4-condition
ruleO-5-trigger
ruleO-5-condition
ruleO-6-trigger
ruleO-6-condition
ruleO-7-trigger
ruleO-7-condition
ruleO-8-trigger
ruleO-8-condition
ruleO-10-a-trigger
ruleO-10-a-condition
ruleO-10-b-trigger
ruleO-10-b-condition
ruleO-14-trigger
ruleO-14-condition
ruleO-15-trigger
ruleO-15-condition
ruleO-16-trigger
ruleO-16-condition
ruleO-17-trigger
ruleO-17-condition
ruleO-18-trigger

ruleO-18-condition
ruleO-19-a-trigger
ruleO-19-a-condition
ruleO-19-b-trigger
ruleO-19-b-condition
ruleO-19-c-trigger
ruleO-19-c-condition
ruleO-19-d-trigger
ruleO-19-d-condition
ruleO-20-trigger
ruleO-20-condition
ruleO-22-trigger
ruleO-22-condition
ruleO-23-trigger
ruleO-23-condition
ruleO-24-trigger
ruleO-24-condition
ruleO-25-a-trigger
ruleO-25-a-condition
ruleO-25-b-trigger
ruleO-25-b-condition
ruleO-26-a-trigger
ruleO-26-a-condition
ruleO-26-b-trigger
ruleO-26-b-condition
ruleO-26-c-trigger
ruleO-26-c-condition
rule5-trigger
rule5-condition
rule9-trigger
rule9-condition

File: equip.lsp

Rule Definitions

rule6-trigger
rule6-condition
rule7-trigger
rule7-condition
rule8-trigger
rule8-condition
rule12-trigger

rule12-condition
rule13-trigger
rule13-condition
rule14-trigger
rule14-condition
rule15-trigger
rule15-condition
rule18-trigger
rule18-condition
rule19-trigger
rule19-condition
rule20-trigger
rule20-condition
rule21-trigger
rule21-condition
rule23-trigger
rule23-condition

File: expansio.lsp

Rule Definitions

ruleE-1-trigger
ruleE-1-condition
ruleE-2-a-trigger
ruleE-2-a-condition
ruleE-2-b-trigger
ruleE-2-b-condition
ruleE-2-c-trigger
ruleE-2-c-condition
ruleE-3-trigger
ruleE-3-condition
ruleE-1-1-1-a-trigger
ruleE-1-1-1-a-condition
ruleE-1-1-1-b-trigger
ruleE-1-1-1-b-condition
ruleE-1-1-1-c-trigger
ruleE-1-1-1-c-condition
ruleE-1-1-1-d-trigger
ruleE-1-1-1-d-condition
ruleE-1-1-1-e-trigger
ruleE-1-1-1-e-condition
ruleE-1-1-2-trigger

ruleE-1-1-2-condition
ruleE-1-3-1-a-1-trigger
ruleE-1-3-1-a-1-condition
ruleE-1-3-1-a-2-trigger
ruleE-1-3-1-a-2-condition
ruleE-1-3-1-b-trigger
ruleE-1-3-1-b-condition
ruleE-1-3-1-c-trigger
ruleE-1-3-1-c-condition

File: kb.lsp

Rule Set Definitions
Rule Set Rules

constraint-rules

rule1-trigger
rule1-condition
rule2-trigger
rule2-condition
rule3-trigger
rule3-condition
rule4-trigger
rule4-condition
rule5-trigger
rule5-condition
rule6-trigger
rule6-condition
rule7-trigger
rule7-condition
rule8-trigger
rule8-condition
rule9-trigger
rule9-condition
rule11-trigger
rule11-condition
rule12-trigger
rule12-condition
rule13-trigger
rule13-condition
rule14-trigger
rule14-condition

rule15-trigger
rule15-condition
rule16-trigger
rule16-condition
rule17-trigger
rule17-condition
rule18-trigger
rule18-condition
rule19-trigger
rule19-condition
ruleH111a-trigger
ruleH111a-condition
ruleH111b-trigger
ruleH111b-condition
ruleH121-trigger
ruleH121-condition
ruleK221-trigger
ruleK221-condition
ruleK222-trigger
ruleK222-condition
ruleK223-trigger
ruleK223-condition
ruleK224-trigger
ruleK224-condition
ruleO-6-trigger
ruleO-6-condition
ruleO-7-trigger
ruleO-7-condition
ruleO-8-trigger
ruleO-8-condition
ruleO-10-a-trigger
ruleO-10-a-condition
ruleO-10-b-trigger
ruleO-10-b-condition
ruleO-14-trigger
ruleO-14-condition
ruleO-15-trigger
ruleO-15-condition
ruleO-16-trigger
ruleO-16-condition
ruleO-17-trigger
ruleO-17-condition
ruleO-18-trigger

ruleO-18-condition
ruleO-19-a-trigger
ruleO-19-a-condition
ruleO-19-b-trigger
ruleO-19-b-condition
ruleO-19-c-trigger
ruleO-19-c-condition
ruleO-19-d-trigger
ruleO-19-d-condition
ruleO-20-trigger
ruleO-20-condition
ruleO-22-trigger
ruleO-22-condition
ruleO-23-trigger
ruleO-23-condition
ruleO-24-trigger
ruleO-24-condition
ruleO-25-a-trigger
ruleO-25-a-condition
ruleO-25-b-trigger
ruleO-25-b-condition
ruleO-26-a-trigger
ruleO-26-a-condition
ruleO-26-b-trigger
ruleO-26-b-condition
ruleO-26-c-trigger
ruleO-26-c-condition
ruleE-1-trigger
ruleE-1-condition
ruleE-2-a-trigger
ruleE-2-a-condition
ruleE-2-b-trigger
ruleE-2-b-condition
ruleE-2-c-trigger
ruleE-2-c-condition
ruleE-3-trigger
ruleE-3-condition
ruleE-1-1-1-a-trigger
ruleE-1-1-1-a-condition
ruleE-1-1-1-b-trigger
ruleE-1-1-1-b-condition
ruleE-1-1-1-c-trigger
ruleE-1-1-1-c-condition

ruleE-1-1-1-d-trigger
ruleE-1-1-1-d-condition
ruleE-1-1-1-e-trigger
ruleE-1-1-1-e-condition
ruleE-1-1-2-trigger
ruleE-1-1-2-condition
ruleE-1-3-1-a-1-trigger
ruleE-1-3-1-a-1-condition
ruleE-1-3-1-a-2-trigger
ruleE-1-3-1-a-2-condition
ruleE-1-3-1-b-trigger
ruleE-1-3-1-b-condition
ruleE-1-3-1-c-trigger
ruleE-1-3-1-c-condition
ruleV-1-trigger
ruleV-1-condition
ruleV-2-trigger
ruleV-2-condition
ruleV-3-trigger
ruleV-3-condition
ruleV-4-trigger
ruleV-4-condition
ruleV-5-trigger
ruleV-5-condition
ruleV-6-trigger
ruleV-6-condition
ruleV-7-trigger
ruleV-7-condition
ruleV-8-trigger
ruleV-8-condition
ruleV-9-trigger
ruleV-9-condition
ruleV-10-trigger
ruleV-10-condition
ruleV-11-trigger
ruleV-11-condition
ruleV-12-trigger
ruleV-12-condition
ruleV-13-trigger
ruleV-13-condition
ruleV-14-trigger
ruleV-14-condition
ruleV-15-trigger

ruleV-15-condition
ruleV-17-trigger
ruleV-17-condition
ruleI-1-5-13-trigger
ruleI-1-5-13-condition
ruleI-1-5-16-trigger
ruleI-1-5-16-condition
ruleR-2-a-trigger
ruleR-2-a-condition
ruleR-2-b-trigger
ruleR-2-b-condition
ruleR-3-trigger
ruleR-3-condition
ruleF-1-trigger
ruleF-1-condition
ruleF-2-a-trigger
ruleF-2-a-condition
ruleF-2-b-trigger
ruleF-2-b-condition
ruleF-2-c-trigger
ruleF-2-c-condition
ruleF-3-trigger
ruleF-3-condition
ruleF-1-1-2-trigger
ruleF-1-1-2-condition
ruleF-1-3-1-a-1-trigger
ruleF-1-3-1-a-1-condition
ruleF-1-3-1-a-2-trigger
ruleF-1-3-1-a-2-condition
ruleF-1-3-1-b-trigger
ruleF-1-3-1-b-condition
ruleF-1-3-1-c-trigger
ruleF-1-3-1-c-condition
rule20-trigger
rule20-condition
rule21-trigger
rule21-condition
ruleO-4-trigger
ruleO-4-condition
ruleO-5-trigger
ruleO-5-condition
ruleV-16-a-trigger
ruleV-16-a-condition

ruleV-16-b-trigger
ruleV-16-b-condition
ruleN-1-trigger
ruleN-1-condition
ruleN-2-trigger
ruleN-2-condition
rule22-trigger
rule22-condition
rule23-trigger
rule23-condition
remove-duals
remove-duplicates1
remove-duplicates2
perform-subsumption-physical1
perform-subsumption-physical2
perform-subsumption-specification
perform-subsumption-or-rules1
perform-subsumption-or-rules2
cache-failed-check-conditions

Rule Definitions

ruleH111a-trigger
ruleH111a-condition
ruleH111b-trigger
ruleH111b-condition
ruleH121-trigger
ruleH121-condition
ruleK221-trigger
ruleK221-condition
ruleK222-trigger
ruleK222-condition
ruleK223-trigger
ruleK223-condition
ruleK224-trigger
ruleK224-condition
remove-duals
remove-duplicates1
remove-duplicates2
perform-subsumption-physical1
perform-subsumption-physical2
perform-subsumption-specification
perform-subsumption-or-rules1

perform-subsumption-or-rules2
cache-failed-check-conditions

File: obj-rule.lsp

Rule Set Definitions
Rule Set Rules

drain-rules
form-penetration-assertion1
add-to-drain-number1
add-to-drain-number2
assert-drainage-area-drain-overlap
form-roof-overflow-drain-assoc1
scupper-drain-assoc2

overflow-drain-rules
form-roof-overflow-drain-assoc2

vent-shaft-rules
form-penetration-assertion1

sump-rules
associate-drain-object

expansion-joint-ruleset
clip-to-roof-footprints
cover-structural-exp-joints

area-divider-ruleset
clip-to-roof-footprints

structural-ruleset
find-support-for-beams
find-center-for-columns
find-support-for-joists1
find-support-for-joists2
find-end-points-for-joists1
find-end-points-for-joists2

roof-footprints-ruleset
initialize-drain-number
initialize-roof-drainage-coverage-area

form-penetration-assertion2
form-penetration-assertion3

two-slope-das-ruleset
assert-complete-overlap-for-drainage-areas1
form-equipment-da-assertions1

one-slope-das-ruleset
subtract-drainage-area-from-roof-coverage1
subtract-drainage-area-from-roof-coverage2
assert-complete-overlap-for-drainage-areas2
assert-drainage-area-drain-overlap

four-slope-das-ruleset
subtract-drainage-area-from-roof-coverage1
subtract-drainage-area-from-roof-coverage2
assert-drainage-area-drain-overlap

walkway-rules
form-close-to-walkway-assertions2
form-adjacent-walkway-assertions

equipment-rules
form-equipment-da-assertions2
form-close-to-walkway-assertions1

scupper-ruleset
make-scupper-drain-assoc1

delete-roof-footprints-ruleset
delete-assoc-footprint-slices
delete-assoc-edges
delete-assoc-wall-segments

delete-roof-footprint-slices-ruleset

delete-roof-edge-ruleset

delete-wall-segment-ruleset
delete-wall-assoc1
delete-wall-assoc2
delete-wall-assoc3

deleted-column-line-ruleset

delete-col-line

Rule Definitions

delete-col-line
make-scupper-drain-assoc1
make-scupper-drain-assoc2
delete-wall-assoc1
delete-wall-assoc2
delete-wall-assoc3
delete-assoc-footprint-slices
delete-assoc-edges
delete-assoc-wall-segments
form-equipment-da-assertions1
form-equipment-da-assertions2
form-close-to-walkway-assertions1
form-close-to-walkway-assertions2
form-adjacent-walkway-assertions
find-center-for-columns
find-end-points-for-joists1
find-end-points-for-joists2
find-support-for-beams
find-support-for-joists1
find-support-for-joists2
form-penetration-assertion1
form-penetration-assertion2
form-penetration-assertion3
associate-drain-object
assert-complete-overlap-for-drainage-areas1
assert-complete-overlap-for-drainage-areas2
assert-drainage-area-drain-overlap
initialize-roof-drainage-coverage-area
subtract-drainage-area-from-roof-coverage1
subtract-drainage-area-from-roof-coverage2
initialize-drain-number
add-to-drain-number1
add-to-drain-number2
clip-to-roof-footprints
cover-structural-exp-joints
form-roof-overflow-drain-assoc1
form-roof-overflow-drain-assoc2

File: roof.lsp

Rule Definitions

ruleR-2-a-trigger
ruleR-2-a-condition
ruleR-2-b-trigger
ruleR-2-b-condition
ruleR-3-trigger
ruleR-3-condition

File: scuppers.lsp

ruleN-1-trigger
ruleN-1-condition
ruleN-2-trigger
ruleN-2-condition

File: vents.lsp

rule16-trigger
rule16-condition
rule11-trigger
rule11-condition
ruleV-1-trigger
ruleV-1-condition
ruleV-2-trigger
ruleV-2-condition
ruleV-3-trigger
ruleV-3-condition
ruleV-4-trigger
ruleV-4-condition
ruleV-5-trigger
ruleV-5-condition
ruleV-6-trigger
ruleV-6-condition
ruleV-7-trigger
ruleV-7-condition
ruleV-8-trigger
ruleV-8-condition
ruleV-9-trigger
ruleV-9-condition
ruleV-10-trigger

ruleV-10-condition
ruleV-11-trigger
ruleV-11-condition
ruleV-12-trigger
ruleV-12-condition
ruleV-13-trigger
ruleV-13-condition
ruleV-14-trigger
ruleV-14-condition
ruleV-15-trigger
ruleV-15-condition
ruleV-16-a-trigger
ruleV-16-a-condition
ruleV-16-b-trigger
ruleV-16-b-condition
ruleV-17-trigger
ruleV-17-condition
ruleI-1-5-13-trigger
ruleI-1-5-13-condition
ruleI-1-5-16-trigger
ruleI-1-5-16-condition

Appendix D: Alphabetical Listing of Goldworks III Lisp Functions

	Function Name	File Name
A	activate-rules-by-tasks	review.lsp
	adjacent	geometry.lsp
	adjacent-cc	geometry.lsp
	adjacent-on-edge	geometry.lsp
	adjacent-rc	geometry.lsp
	adjacent-rr	geometry.lsp
	align-adjust-width-rr	snap.lsp
	aligned	geometry.lsp
	all-frame-instances	cma-fn.lsp
	apply-lisp-functions	cma-fn.lsp
	area-of	geometry.lsp
	area-of-c	geometry.lsp
	area-of-rc	geometry.lsp
	area-of-rc*	geometry.lsp
	area-of-rc**	geometry.lsp
	assert-subtask-list	cma-fn.lsp
	assess-spacing	obj-fn.lsp
	assess-spacing*	obj-fn.lsp
	atomic-listp	violate.lsp
B	binding-list-match	kb.lsp
	border-order	geometry.lsp
	build-rule-object-type-list	prevdet.lsp
	build-rule-task-list	prevdet.lsp
C	cat-explanation-terms	violate.lsp
	cat-explanation-terms-2	violate.lsp
	check-all-borders	geometry.lsp

check-and-activate-tasklist	cma-fn.lsp
check-colinearity-overlap-segments	geometry.lsp
check-colinearity-overlap-segments*	geometry.lsp
check-corners	obj-fn.lsp
check-distance-intervals	obj-fn.lsp
check-intersection	prevdet.lsp
check-walkway-objects	geometry.lsp
checked-before	kb.lsp
checked-before-dual	kb.lsp
classify-corner	obj-fn.lsp
clear-all	cma-fn.lsp
clip-or-extend-rc-objects	obj-fn.lsp
clip-or-extend-to-roof	obj-fn.lsp
clip-or-extend-to-roof*	obj-fn.lsp
combine	cma-fn.lsp
combine-area-horizontally	decomp.lsp
combine-area-vertically	decomp.lsp
combine-horizontal-areas	decomp.lsp
combine-horizontal-areas*	decomp.lsp
combine-vertical-areas	decomp.lsp
combine-vertical-areas*	decomp.lsp
complete-expansion-joint-slots	obj-fn.lsp
complete-extent-overlap	geometry.lsp
complete-overlap	geometry.lsp
complete-overlap-cc	geometry.lsp
complete-overlap-rc	geometry.lsp
complete-overlap-rc*	geometry.lsp
complete-overlap-rr	geometry.lsp
complete-overlap-rr*	geometry.lsp
compute-distance	geometry.lsp
compute-distance-cc	geometry.lsp
compute-distance-rc	geometry.lsp
compute-distance-rr	geometry.lsp
connected?	geometry.lsp
connected?*	geometry.lsp
convert-from-string	cma-main.lsp
count	cma-fn.lsp
count-objects	cma-fn.lsp
create-low-point-drain	obj-fn.lsp

	draw-point	geometry.lsp
E	east-of	geometry.lsp
	east-of-extent	geometry.lsp
	edge-point-dist	geometry.lsp
	edgex1	geometry.lsp
	edgex2	geometry.lsp
	edgey1	geometry.lsp
	edgey2	geometry.lsp
	equal-extents	snap.lsp
	exceeds-max-distance-p	geometry.lsp
F	filter	cma-fn.lsp
	filter-deactivated-tasks	update.lsp
	filter-heights	geometry.lsp
	filter-mapcar	cma-fn.lsp
	filter-out-rectangles	decomp.lsp
	filter-recently-activated	update.lsp
	find-nearest-adjacent-edge	snap.lsp
	first-highest-priority-task	prevdet.lsp
	form-binding	prevdet.lsp
	form-binding*	prevdet.lsp
	form-complete-overlap-remainder	decomp.lsp
	form-one-corner-remainder	decomp.lsp
	form-one-side-remainder	decomp.lsp
	form-two-corner-remainder	decomp.lsp
	form-two-side-remainder	decomp.lsp
	frame-ancestor	cma-fn.lsp
	frame-ordered	cma-fn.lsp
	frame-ordered*	cma-fn.lsp
	frame-ordered**	cma-fn.lsp
G	get-active-rules	prevdet.lsp
	get-active-rules-for-object-place	prevdet.lsp
	get-all-dtm-activations	cma-main.lsp
	get-binding	violate.lsp
	get-bounding-points	obj-fn.lsp
	get-edge	geometry.lsp

make-column-id	obj-fn.lsp
make-columns	obj-fn.lsp
make-coord-info	geometry.lsp
make-expansion-joint-points	obj-fn.lsp
make-explanation	violate.lsp
make-explanation-list	violate.lsp
make-extent	geometry.lsp
make-extent*	geometry.lsp
make-footprint-slices	obj-fn.lsp
make-footprint-slices*	obj-fn.lsp
make-h-slices	decomp.lsp
make-h-slices*	decomp.lsp
make-horizontal-borders	geometry.lsp
make-horizontal-borders*	geometry.lsp
make-joint-points*	obj-fn.lsp
make-joint-points-h**	obj-fn.lsp
make-joint-points-v**	obj-fn.lsp
make-line	obj-fn.lsp
make-new-antecedent	prevdet.lsp
make-new-consequent	prevdet.lsp
make-object-instance	cma-fn.lsp
make-object-list	violate.lsp
make-object-list	violate.lsp
make-object-place-ruleset	prevdet.lsp
make-object-select-ruleset	prevdet.lsp
make-od-rule	prevdet.lsp
make-penetration-id	obj-fn.lsp
make-review-rules	review.lsp
make-review-rules-for-task-subtree	review.lsp
make-roof-drains-id	obj-fn.lsp
make-roof-edges	obj-fn.lsp
make-roof-walls	obj-fn.lsp
make-roof-walls*	obj-fn.lsp
make-select-violation-action	violate.lsp
make-slice-id	obj-fn.lsp
make-v-slices	decomp.lsp
make-v-slices*	decomp.lsp
make-v-slices**	decomp.lsp
make-vertical-borders	geometry.lsp

	order-by-tasks-select	violate.lsp
P	point-distance	geometry.lsp
	point-in-extent	geometry.lsp
	point-in-rect	geometry.lsp
	point-in-rect1	geometry.lsp
	point-strictly-in-extent	geometry.lsp
	pointx	geometry.lsp
	pointy	geometry.lsp
	pop-border-list	geometry.lsp
	pop-border-list*	geometry.lsp
	print-elapsed-time	cma-fn.lsp
Q		
R	recently-activated	cma-main.lsp
	recently-activated*	cma-main.lsp
	rect-comp-point-dist	geometry.lsp
	rect-comps-dist	geometry.lsp
	rect-comps-dist-aux	geometry.lsp
	rect-points-touch-circle	geometry.lsp
	rect-segments-touch-circle	geometry.lsp
	remove-nils	cma-main.lsp
	remove-rectangle	decomp.lsp
	rule-task-pair-compare	violate.lsp
S	segment-within-distance	geometry.lsp
	segment-within-distance*	geometry.lsp
	set-start-time	cma-fn.lsp
	simple-span-extent	geometry.lsp
	simple-span-extent	geometry.lsp
	simple-span-extent-rr	geometry.lsp
	simple-span-rr	geometry.lsp
	snap-drainage-area	snap.lsp
	snap-four-slope-das	snap.lsp
	snap-one-slope-das	snap.lsp
	snap-to-fit-circle-point	snap.lsp
	sort-by-priority-reverse	violate.lsp

Appendix E: Alphabetical Listing of Autolisp Functions

	Function	File
A	action-depends-on-object	ac-shell.lsp
	activate-task	ac-shell.lsp
	active-state-string	ac-shell.lsp
	add-if-not-null	ac-shell.lsp
	add-task	ac-shell.lsp
	all-spaces	ac-expl.lsp
	attribs-list-click-callback	attribs.lsp
B	build-constraint-block	ac-shell.lsp
	build-constraint-block-filter	ac-shell.lsp
	build-critique-layer-list	ac-shell.lsp
C	c:done	ac-shell.lsp
	call-gcl	ac-shell.lsp
	change-attribs	attribs.lsp
	change-object-slot-values	ac-shell.lsp
	change-slots	slots.lsp
	change-slots*	slots.lsp
	clean-up-rc	handlers.lsp
	clean-up-rc*	handlers.lsp
	clean-up-segment	handlers.lsp
	clear-violation	ac-shell.lsp
	clear-violation-aux	ac-shell.lsp
	compute-ww-rc	handlers.lsp
	compute-ww-side-1	handlers.lsp
	compute-ww-side-2	handlers.lsp
	continue-path-1	handlers.lsp
	continue-path-2	handlers.lsp

	convert-da-to-rc	handlers.lsp
	convert-pline-to-rc	handlers.lsp
	create-ac-units-curbed	handlers.lsp
	create-ac-units-sleeps	handlers.lsp
	create-and-color-constraint-layer	ac-shell.lsp
	create-and-color-constraint-layers	ac-shell.lsp
	create-area-dividers	handlers.lsp
	create-attic-vents	handlers.lsp
	create-circular-object	handlers.lsp
	create-column-lines	handlers.lsp
	create-columns	handlers.lsp
	create-exhaust-fans	handlers.lsp
	create-exp-joints	handlers.lsp
	create-fans	handlers.lsp
	create-four-slope-das	handlers.lsp
	create-hatches	handlers.lsp
	create-hot-stacks	handlers.lsp
	create-masonry-chims	handlers.lsp
	create-mech-units	handlers.lsp
	create-new-object	ac-shell.lsp
	create-new-objects	ac-shell.lsp
	create-one-slope-das	handlers.lsp
	create-overflow-drains	handlers.lsp
	create-power-vents	handlers.lsp
	create-rectangular-object	handlers.lsp
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